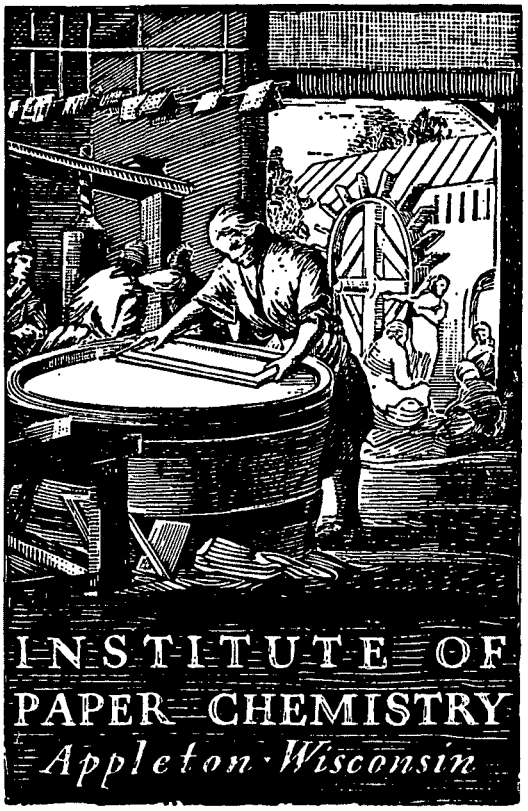

BARK AND WOOD PROPERTIES OF PULPWOOD SPECIES AS RELATED TO SEPARATION AND SEGREGATION OF CHIP/BARK MIXTURES

Project 3212

Report Three

A Progress Report

to

MEMBERS OF GROUP PROJECT 3212

June 15, 1975

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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Abitibi Paper Company, Ltd.

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The Procter & Gamble Company

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

BARK AND WOOD PROPERTIES OF PULPWOOD SPECIES AS RELATED TO SEPARATION AND SEGREGATION OF CHIP/BARK MIXTURES

SUMMARY

White spruce has a wood specific gravity of 0.34 and an average bark specific gravity of 0.39. Bark extractives levels averaged 16%. Morphologically, the bark contains large numbers of sieve cells, some sclereids but no fiber. Pulping white spruce bark gave a solids yield of 20-22%. Screening of the bark pulp resulted in approximately 90% of the solids passing through the 100-mesh screen. The fraction retained on the 60- and 100-mesh screens contained 7 grams of sieve cells and 1.5 grams of sclereids per 100 grams of bark pulped. It appears separation and segregation of white spruce wood and bark chip mixtures could be accomplished in several ways. This species, in earlier research, responded the best of six species tested to chemical and thermal methods of reducing adhesion. Segregation through water flotation is possible although relatively long time periods would be required. Hammermilling resulted in only a 23% reduction in bark levels but it is possible that a quick segregation could be made by screening, hammermilling the fractions high in bark and rescreening.

Balsam fir, based upon values in the literature and measurement data from trees sampled as part of the project, has an average wood specific gravity of 0.34 and a bark specific gravity of 0.40. Extractives levels for wood and bark were 2.0 and 19.5%, respectively. Pulping balsam fir bark produced a solids yield of approximately 26%. Of this, approximately 2% were sieve cells and 12% were sclereids. There was no fiber produced. Considering the large number of sclereids plus a high level of extractives, removal of at least part of the bark appears desirable. Segregation through water flotation is possible but long time periods

are again required. The most useful approach appears to be the use of a "screening-hammermilling-rescreening" procedure. In hammermilling tests run at the Institute, a 44% reduction in bark levels was achieved.

Jack pine had a wood specific gravity of 0.39 and a bark specific gravity of 0.41. Extractives levels were 3.9 and 15.3% for the wood and bark, respectively. Morphologically, the bark contained mostly sieve cells. Sieve cells act mainly as filler material and possibly as a bonding material. There are no fibers present in the bark of jack pine. Pulping jack pine bark gave a solids yield of approximately 19%. Screening the pulp resulted in 4% sieve cells and <1% phellem cells remaining on the 60- and 100-mesh screens. Because of the thin nature of the bark and lack of sclereids, this species is a good prospect for pulping with the wood. Water flotation is not a good technique for segregation of wood/bark chip mixtures because of similarities in the density of wood and bark at the same moisture content. The screening-hammermilling-rescreening approach has some merit and it is possible improvements in screening would result in even better segregation. Compression debarking also appears worthy of consideration with a 95% wood recovery and a residual bark content of 3% out of an original bark content of 8% in one trial.

Eastern cottonwood was found to have a wood specific gravity of 0.38 and a bark specific gravity of 0.31. Extractives levels were 1.4 and 7.9%, respectively, for the wood and bark. Morphologically, eastern cottonwood bark does contain fiber. The bark, when pulped, had a solids yield of 34-37%. When screened, approximately 10% of the solids were retained on the 60- and 100-mesh screens, most of which was fiber. Eastern cottonwood was a difficult species to segregate through the techniques investigated. Because of the similarities of wood and bark densities at various moisture contents, water flotation is not a feasible

approach. Hammermilling resulted in only 18% of the bark being removed. However, most of the bark removed was outer bark, leaving behind the inner bark, which is high in fiber. Eastern cottonwood also responded well in earlier investigations to the reduction of wood/bark adhesion using chemical and thermal methods.

INTRODUCTION

Whole-tree chipping is one of the most promising approaches for improved forest utilization. Not only does the procedure make possible efficient utilization of hardwood stands but whole-tree chipping is an important part of most short-rotation management systems presently under development. Species-to-species variation in bark characteristics is turning out to be at least as great as wood property variation. This further emphasizes our previously discussed philosophy that there is no single "best solution" to the bark problem. The major objective of Project 3212 is to provide interested companies with a concise package of data for the more important pulpwood species of the United States. Such data are expected to allow the formulation of appropriate solutions to specific bark problems on a mill-by-mill basis.

During 1973, when pulp was in short supply, many companies began using increasing amounts of whole-tree chips containing relatively high levels of bark (12-15%) without knowing the chemistry or morphology of the bark being pulped. Many unexpected problems developed as the result of this "try and see" approach. Company experience in the use of whole-tree chips is difficult to evaluate, partly because of the other changes that were taking place at the same time (use of new wood species, recycling of water, etc.) whole-tree chips were introduced to mill operations. The most common complaints, in addition to increased dirt in the final product, include excessive equipment wear (valves, refiners, screens, etc.), decreased pulp yield, increased chemical costs, frequent digester plugging, and increased evaporator scaling. Our preliminary studies indicate that there may be additional subtle changes in sheet properties (drainage, strength, etc.) associated with the use of bark that will influence machine speed. The complaints experienced to date suggest that the use of whole-tree chips without bark removal

will require increased digester capacity, improved chip washing and pulp washing procedures, increased cleaner capacity and increased recovery furnace capacity.

In addition to fiber supply problems, the rapidly changing environmental, energy, and pulp demand situation has made it clear that it is important to define the bark problem rather than to use the expedient "try and see" approach. More and more, it appears that what will be required is the development of a highly flexible chip handling procedure that will maximize the advantages associated with whole-tree chipping and at the same time minimize the negative aspects that accompany the pulping of bark. Under some circumstances, modest fiber loss appears acceptable in view of reduced mill problems and the energy value of the bark and low quality fiber. Considerable emphasis needs to be placed on system flexibility. Such flexibility is required to allow for changes in the species mix and the seasonal variation in the effectiveness of chip/bark segregation procedures. It may also be economically useful to use the suggested flexibility to allow the inclusion of the maximum amount of bark when pulp demand is high (sellers' market) and quality standards can be relaxed.

Progress Report One provided cooperating companies with information on the bark characteristics of quaking aspen, sugar maple, white birch and northern red oak. Progress Report Two provided similar information for loblolly pine, slash pine, Douglas-fir, and western hemlock. The report that follows presents information on the fundamental properties of the bark of white spruce, balsam fir, jack pine, and eastern cottonwood. The information was obtained from a comprehensive literature search combined with measurement data taken on a limited number of representative pulpwood-sized trees of each species. In an effort to make the information as useful as possible, the format for each report and for each species

is exactly the same. Use of such a procedure results in some repetition but makes the information on each species a study in itself and not dependent upon other reports.

TREE GROWTH AND BARK DEVELOPMENT

Tree growth and bark development were covered in Project 3212, Progress Report One. To briefly summarize, a tree grows through elongation and enlargement of the bole and crown (primary growth) and thickening of the bole (secondary growth). The bark consists of the inner bark (secondary phloem), which is partly physiologically active, and the outer bark, which is mainly functionless. Tissues in the inner bark are constantly being developed and the first-formed layers of periderm may be cut off from the vital processes of the tree. This can result in roughened bark which may either be cast off or retained as in the case of deeply fissured trees. In smooth-barked trees the first-formed periderm may persist for many years. Figure 1, taken from Chang (1) illustrates the tissues found in different kinds of bark and is provided, along with the Glossary, to help the reader better understand the bark descriptions that follow.

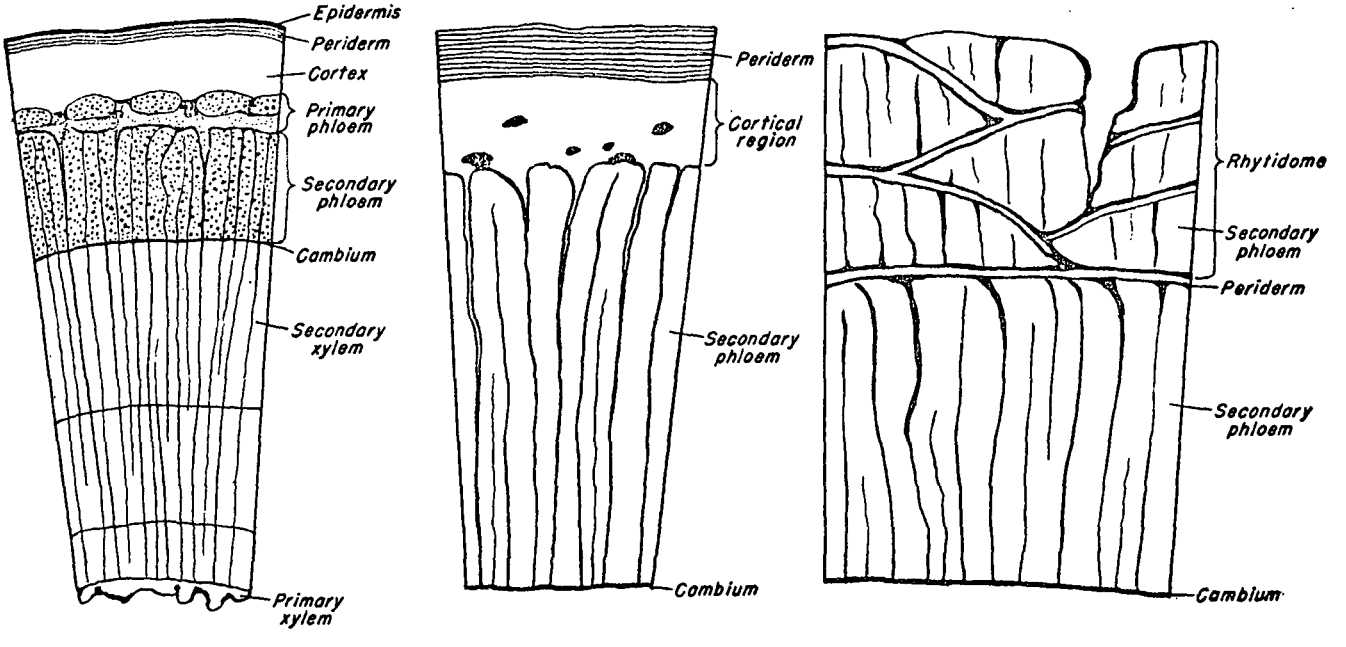

Figure 1. Diagrammatic Drawings Showing the Main Tissue in Different Types of Bark. (1) Cross Section of Young Branch of Stem. (2) Cross Section of Bark Having Persistent Cortex, such as that in the Middle-Aged Balsam Fir and Quaking Aspen. (3) Mature Bark with Rhytidome Formation

EXPERIMENTAL PROCEDURES

The experimental procedures employed have, as much as possible, been standardized and the same methods used for each tree species. Progress Report One should be referred to for complete descriptions of the experimental procedures used.

Tree size and sample location were standardized and utilized trees 7 to 9 inches in diameter at breast height (4-1/2 feet). All measurements were made on samples from the breast high location or from 12 to 18-inch bolts obtained from the area just below the breast high sample.

Specific gravity was determined using a water displacement technique that is a modification of the TAPPI Standard Method, T 18 m-53, and results are expressed in terms of ovendry weight/green volume. The bark micropulping procedure was that of Thode, et al. (2). After micropulping, the bark was rinsed, fiberized in a Waring Blendor and decanted on a sintered glass funnel. It was then put through a series of screens and the material on each screen examined for the type of cellular material it contained.

The wood/bark adhesion method measured shear parallel to the grain on a small, specially prepared sample using the Instron tester. Representative growing and dormant season adhesion samples were immersed in ethyl alcohol immediately after testing for later morphological examination.

Bark strength measurements were made using essentially the same procedure as used in measuring wood/bark adhesion (shear parallel to the grain). Bark toughness measured the energy required to rupture a small bark or wood sample by bending with a force parallel to the diameter of the tree. A "Micro

Pulverizer" was modified to provide a hammermilling test on standard bark and wood chips. After the chips were fed through the pulverizer, they were separated on a series of soil screens and the percentage on each screen calculated.

Basic density of standard wood and bark chips at various moisture contents was determined using a pycnometer and the chemical, heptane, as the displacement medium. Moisture content was calculated as (wet wt.-o.d. wt.)/ o.d. wt. Density was calculated as $(c \cdot d)/[c-(b-a)]$ where:

a = weight of pycnometer + heptane

b = weight of pycnometer + heptane + chip

c = weight of chip (wet — before being placed in heptane)

d = density of heptane.

BARK AND WOOD PROPERTIES OF WHITE SPRUCE
[Picea glauca (Moench) Voss]

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

White spruce has a transcontinental distribution through northern North America. It grows naturally from Newfoundland, Labrador and the northern New England and Lake States area northwestward across Canada to Alaska. In this wide range, white spruce, one of the hardiest conifers, tolerates a wide variety of environmental conditions, from wet insular Nova Scotia to semi-arid areas of Manitoba, extreme temperature ranges, and elevations from sea level to 5000 ft. A variety of soils, and with a considerable range of pH, will support this species. Grey wooded soils, brown forest soils, and podzolized soils prevail throughout the range. The soils vary from heavy clays in the Upper Peninsula of Michigan to the alluvial plains in Alberta where white spruce reaches its best development obtaining heights of 184 ft. Average tree dimensions at maturity are 60-70 ft. in height and 18-24 inches in diameter although heights of 110 ft. are not uncommon.

WOOD AND BARK MORPHOLOGY

Wood

White spruce wood, lustrous, nearly white to pale brown with an indistinct heartwood, is usually straight grained, light to moderately light, and very uniform in appearance. Growth rings are distinct, delineated by the contrast between the latewood and the earlywood of the succeeding ring. The earlywood zone is usually several times wider than the somewhat darker latewood zone.

Xylem of white spruce consists of tracheids aligned in distinct radial rows, uniseriate and fusiform rays, and longitudinal and transverse resin canals.

The tracheids have an average diameter of 25-30 μm and an average length of 3.5 mm. Average cell wall thickness varies from earlywood fibers of less than 1.0 μm to latewood fibers which measure 3-4 μm. Fine and numerous, uniseriate rays are 1-16+ cells in height. Fusiform rays, up to 16+ cells in height, are scattered, with one or rarely two transverse resin canals. Ray tracheids are present in both types of rays and usually restricted to one row on the upper and lower margin. Resin canals are lined with thick-walled epithelial cells and those in the heartwood may occasionally be occluded with tylosoids. The longitudinal resin canals average 50-90 μm in diameter and the transverse, less than 30 μm.

Bark

Ashy-brown with thin small scales, white spruce bark is usually not over 0.5 inch thick. Periderm layers are distinct and sporadic sclerenchyma groups are visible in the inner bark and quite distinct at the outer bark. Rather narrow, the inner bark is generally 1/16-1/8 inch wide. In the trees used in this study, the outer bark accounted for 92% of the total bark thickness by weight. Figure 2 illustrates a cross section of white spruce wood and bark. Appendix Table XXVII describes the trees used in this study.

Anatomical Structure of Mature Bark

The periderm in the outer bark is composed of 2-3 layers of phelloderm, a layer of phellogen and 1-3 layers of thin-walled phellem cells alternating with 1-3 layers of thick-walled "corky" phellem cells. The number of phellem cells in a periderm layer is variable, often over 20 cells. Phellem cells are rectangular in cross section, 10-20 microns and 20-30 microns in radial and tangential dimensions, respectively. Newly-formed phelloderm cells are approximately the same size and merge into the parenchyma cells of the secondary phloem. Occasionally the cells "lignify."

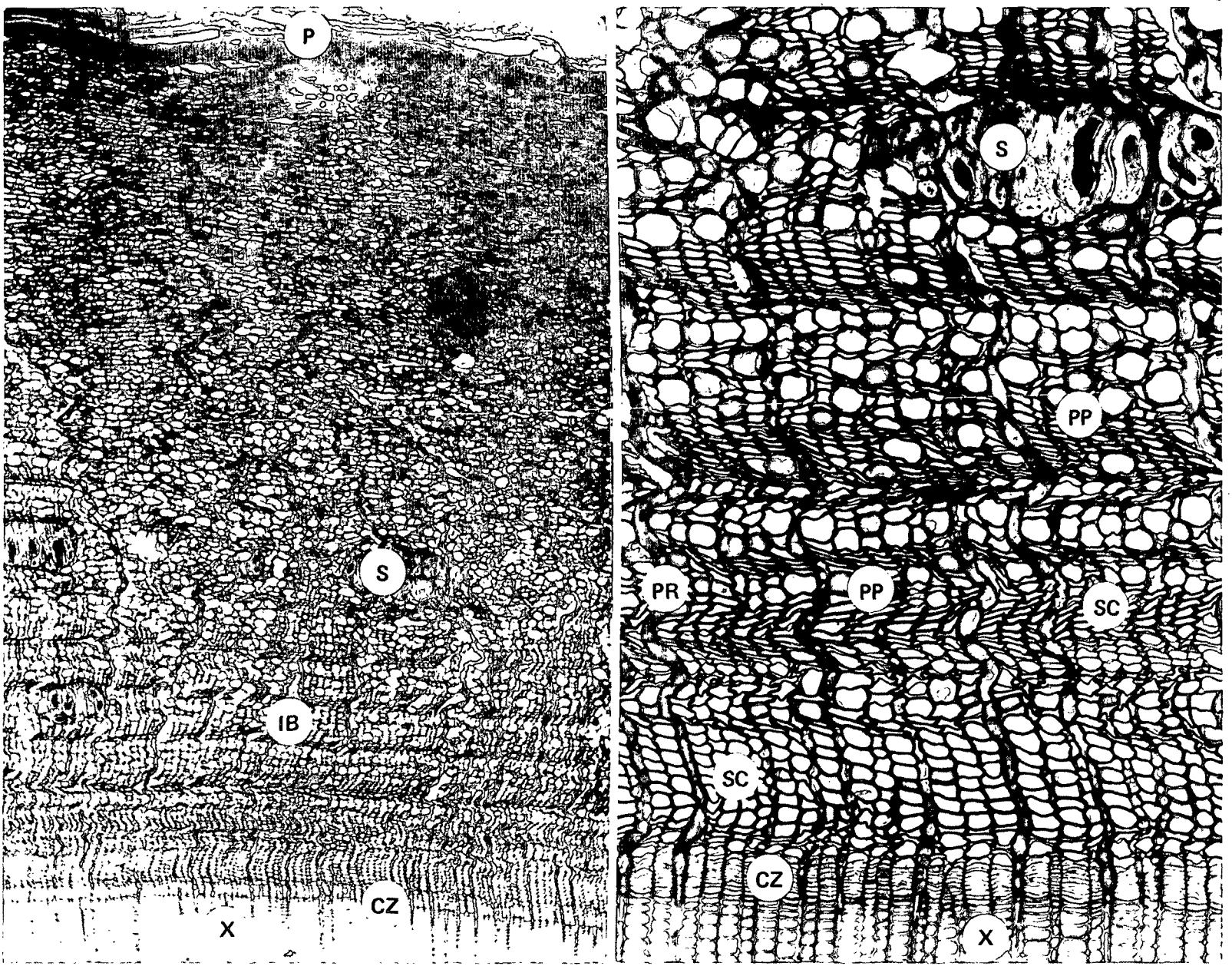

Figure 2. Cross Section of White Spruce. Photomicrograph on Left Shows Xylem (X), Cambium Zone (CZ), Inner Bark (IB) and Periderm (P). Note the Small Groups of Thick-Walled Sclereid Cells (S). Photomicrograph on the Right is a Cross Section of the Inner Bark Showing the General Arrangement of the Secondary Phloem Tissues. Included in the Cross Section are the Xylem (X), Cambium Zome (CZ), Sieve Cells (SC), Phloem Parenchyma (PP), Phloem Rays (PR) and Sclereid Group (S). Magnification — 35X Left, 125X Right

The inner bark (secondary phloem) of white spruce is made up of sieve cells, parenchyma cells, sclereids, ray cells and horizontal resin canals. Sieve cells, usually 3.8 mm long, are aligned in radial rows of approximately 14-16 cells interspersed by 1-3 tangential lines of parenchyma cells. Sieve cells appear rectangular in cross section, their radial and tangential dimensions averaging approximately 10-20 μm and 10-30 μm, respectively, with a cell wall thickness of approximately 1-2 μm. In the outer part of the inner bark, and in the outer bark, the sieve cells are obliterated or crushed. Parenchyma strands are about the same length as the adjacent sieve cells. Individual cells are 50-150 microns high. Sclereids are transformed from the phloem parenchyma and are aggregated in small groups. At the outer part of the inner bark, sclereid groups of 10 or more cells appear sporadically. The size of the larger groups may have a radial dimension of 0.15-3.0 mm, a tangential dimension of 0.5-1.0 mm, and a height of 0.5-2 mm. Individual cells, with diameters of about 15-25+ microns, have very thick walls (25+ μm) and are irregular in shape and sometimes branched. Phloem rays are both uniseriate and fusiform. Uniseriate rays are usually 10-15 cells or 200-300 microns high. Marginal erect cells or albuminous cells are present in almost every ray close to the cambium region. Fusiform rays with horizontal resin canals are common. Usually 2-5 layers of thin-walled epithelial cells line the ducts of the resin canals which average approximately 250 μm in diameter.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and sclereids are expected to be useful in determining the need

and possible methods of separating and segregating wood/bark chip mixtures*. Whenever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table I summarizes the information available on wood and bark of white spruce. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. It should be noted that several of the values in Table I are ovendry weights divided by ovendry volumes. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report under the section Water Flotation Behavior compares the basic density (green weight divided by green volume) of white spruce at several moisture contents.

An average specific gravity (ovendry weight/green volume) of approximately 0.34 appears appropriate for the wood of white spruce. Our limited data do not show much of a difference between heartwood and sapwood although, for the two trees sampled, the sapwood was higher in specific gravity.

The specific gravity of the total (inner + outer) bark of white spruce appears fairly close to that of the wood or perhaps slightly higher. It was impossible to obtain specific gravity measurements on the inner bark because of its extreme thinness. Overall values suggested for use in species comparisons are 0.35 for wood, and 0.43 and 0.39 for outer and total bark.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

TABLE I

WHITE SPRUCE SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood		Bark				Reference and Remarks
Average	Range	Inner	Outer	Total	Range	
0.35	0.30-0.41					Maeglin (3)
				0.45[a]		Millikin (4)
0.35						Isenberg (5)
0.34				0.29		Erickson (6)
				0.38		Fournier & Goulet (7)
0.36	0.32-0.38 (Diam. class 7.6-8.9)					Pronin (8)
0.37	0.31-0.43 (Diam. class 4.6-8.9)					Wahlgren, et al. (9)
0.35						Besley (Canada) (10)
0.34 (Sapwood) 0.28 (Heartwood)		--	0.38	0.43		IPC 3212-6
0.34 (Sapwood) 0.33 (Heartwood)		--	0.48	0.42		IPC 3212-35
0.32						Project 2977 tree No. 1
0.32						Project 2977 tree No. 2
0.41[b]				0.82[b]		Erickson (6)
0.38[b]						Isenberg (5)
				0.65[b]		Harkin & Rowe (11)

[a] Rough estimate based on conversion from lb OD bark per cu ft.
[b] Ovendry weight/ovendry volume.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

A range in levels of extractives in wood from 1.8 to 2.6 has been reported for white spruce (see Table II). For between-species comparisons, an extractives level of 2.2% is suggested for the wood of white spruce. Based upon information obtained from the two trees sampled as part of this project, the bark of white spruce can be expected to have an extractives level of 16%. This relatively high level of extractives might cause problems in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other techniques.

TABLE II

WHITE SPRUCE ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	1.8	Chideester (12)
Wood	2.3	Chideester (12)
Wood	2.6	Rydholm (13)
Bark	18.4	IPC 3212-6
Bark	13.5	IPC 3212-35

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product. The principal elements in the bark of white spruce having an effect on the pulp are sieve cells and sclereids. There are no true fibers in the bark of white spruce.

The short, thin-walled sieve cells (see photomicrographs) could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve cells, would probably be extremely brittle and low in strength. Sieve cells could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of this problem.

Sclereids are short, thick, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. Estimates made of IPC macerated bark samples suggest that sclereids make up 2-4% of the total bark weight. This is a very low level and sclereids should not be much of a problem when the bark of white spruce is included in a pulp mixture.

As a check on pulp yield and the nature of the material produced from white spruce, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table III summarizes the results of this investigation. Micropulping white spruce bark resulted in a yield of 20 to 22% solids. When screened, the coarse screens (60 and 100 mesh) retained most of the sieve cells and about half of the sclereids. The on 150-mesh screen contained mainly sieve cells. The on 200-mesh and through 200-mesh screens had a high percentage of parenchymatous and peridermal cells and most of the remaining sclereids. Figure 3 illustrates the type of material on the 60- and 150-mesh screens.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of brk that is pulped, about 21 grams of solids will result. Of this 21 grams, about 7 grams (7%) of sieve cells and 1.5 grams (1.5%) of sclereids will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

Eskilsson and Hartler (14) and Eskilsson (15), in a comprehensive study on whole-tree pulping in Sweden, found that needles, bark and twigs of spruce gave pulp yields of about 20%, which is similar to IPC results. The consumption of cooking chemicals was considerably higher for these components than for wood and gave pulps that were easily beaten, slow draining, dark and mechanically weak.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species. The

TABLE III

WHITE SPRUCE MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-6	Sample No. 3212-35	Remarks[a]
Yield, % solids	19.9	21.4	
Fraction			
On 60 mesh, %	37.2	32.3	The fraction contained principally sieve cells (80-90%) with a small percentage of sclereids (10-20%) and a trace of parenchymatous cells (< 1%). Length of sieve cells: (1) Arithmetic av. length — 1.47 mm, (2) Weighted av. length — 1.84 mm
On 100 mesh, %	4.4	5.8	The fraction contained a large percentage of sieve cells (70-80%) with small percentages of sclereids (10-20%), parenchymatous cells (< 5%) and thick-walled peridermal cells (< 5%)
On 150 mesh, %	3.4	4.2	The fraction contained a large percentage of sieve cells (50-60%) with smaller percentages of sclereids (20-30%), parenchymatous cells (5-10%) and thick-walled peridermal cells (5-10%)
On 200 mesh, %	4.4	4.9	The fraction contained parenchymatous cells (40-50%), sclereids (20-30%), sieve cells (10-20%) and thick-walled peridermal cells (10-20%)
Through 200 mesh, %	50.6	52.8	The fraction contained large percentages of parenchymatous cells (50-60%), thick-walled peridermal cells (40-50%) with a small percentage of sclereids (5-10%) and a trace of sieve cells (< 1%)

[a]Percentages given are on a dry weight basis.

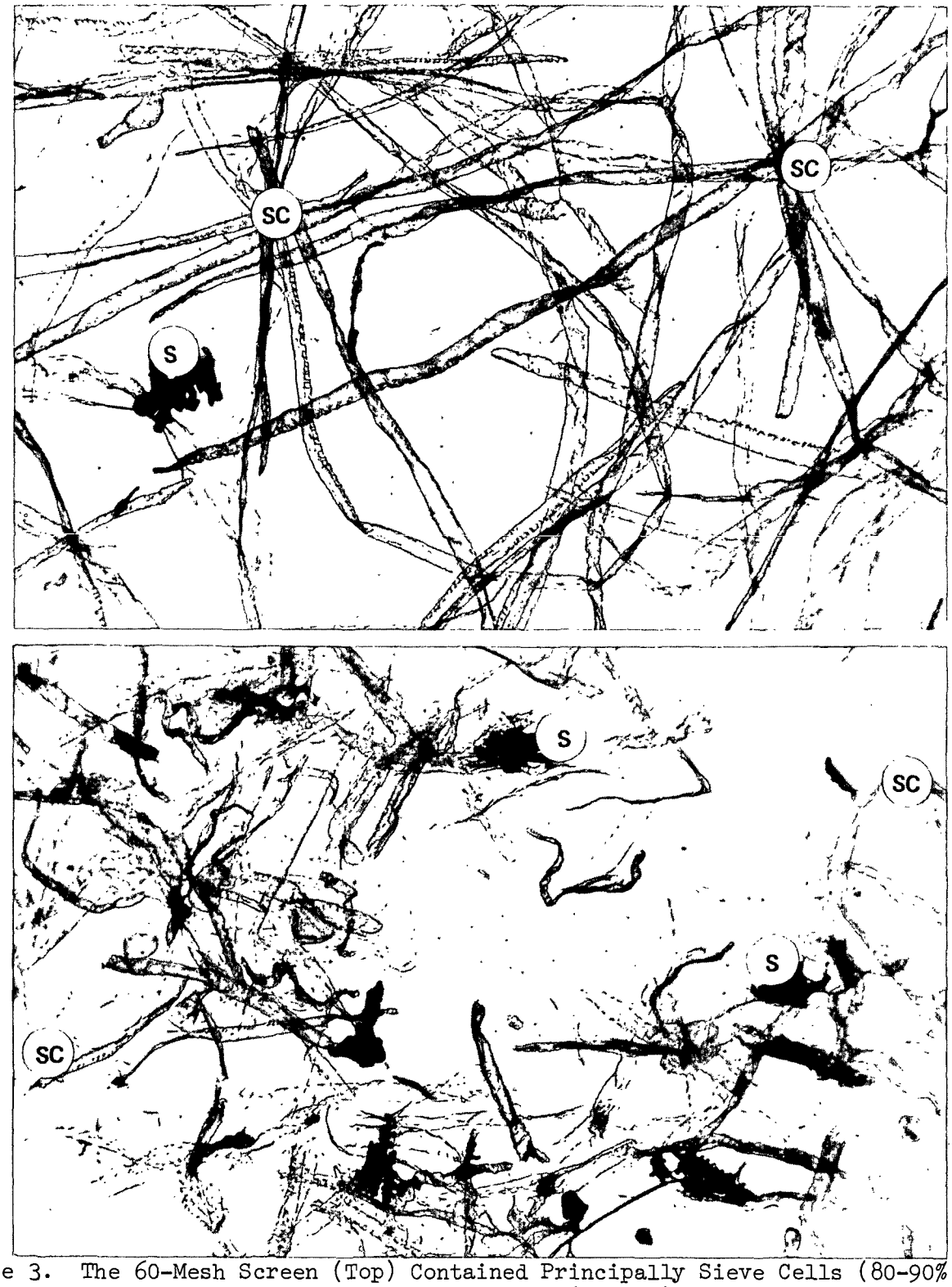

Figure 3. The 60-Mesh Screen (Top) Contained Principally Sieve Cells (80-90%) with a Small Percentage of Sclereids (10-20%). The 150-Mesh Screen (Bottom) Contained a Large Percentage of Sieve Cells (50-60%) with Smaller Percentages of Sclereids (20-30%). Magnification — 75X. Symbols Include Sclereids (S) and Sieve Cells (SC)

same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured for appropriately collected samples. Wood/bark adhesion in white spruce was studied extensively in Project 2929 (Progress Report Three) and the work was not repeated but a summary of the results of earlier investigations follows.

The bark peeling season for white spruce growing in a plantation near The Institute of Paper Chemistry was estimated to have started near the end of April (adhesion values less than 7.5 kg/cm^2) and extended until the beginning of August. Adhesion values during the peeling season varied from 3.4 to 7.1 and averaged 4.4 kg/cm^2 while during the dormant season they averaged 10.3 kg/cm^2.

The zone of failure started out during the spring dormant season in the inner bark sieve and parenchyma cells. At the beginning of the peeling season the failure began to occur in the cambium zone and in the newly-formed xylem elements just outside the cambium. At the conclusion of the peeling season the zone of failure moved back out to the inner bark region. Figure 4 illustrates the zones of failure for white spruce.

As a result of measurement data taken on the species included in Appendix Table XXVIII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner

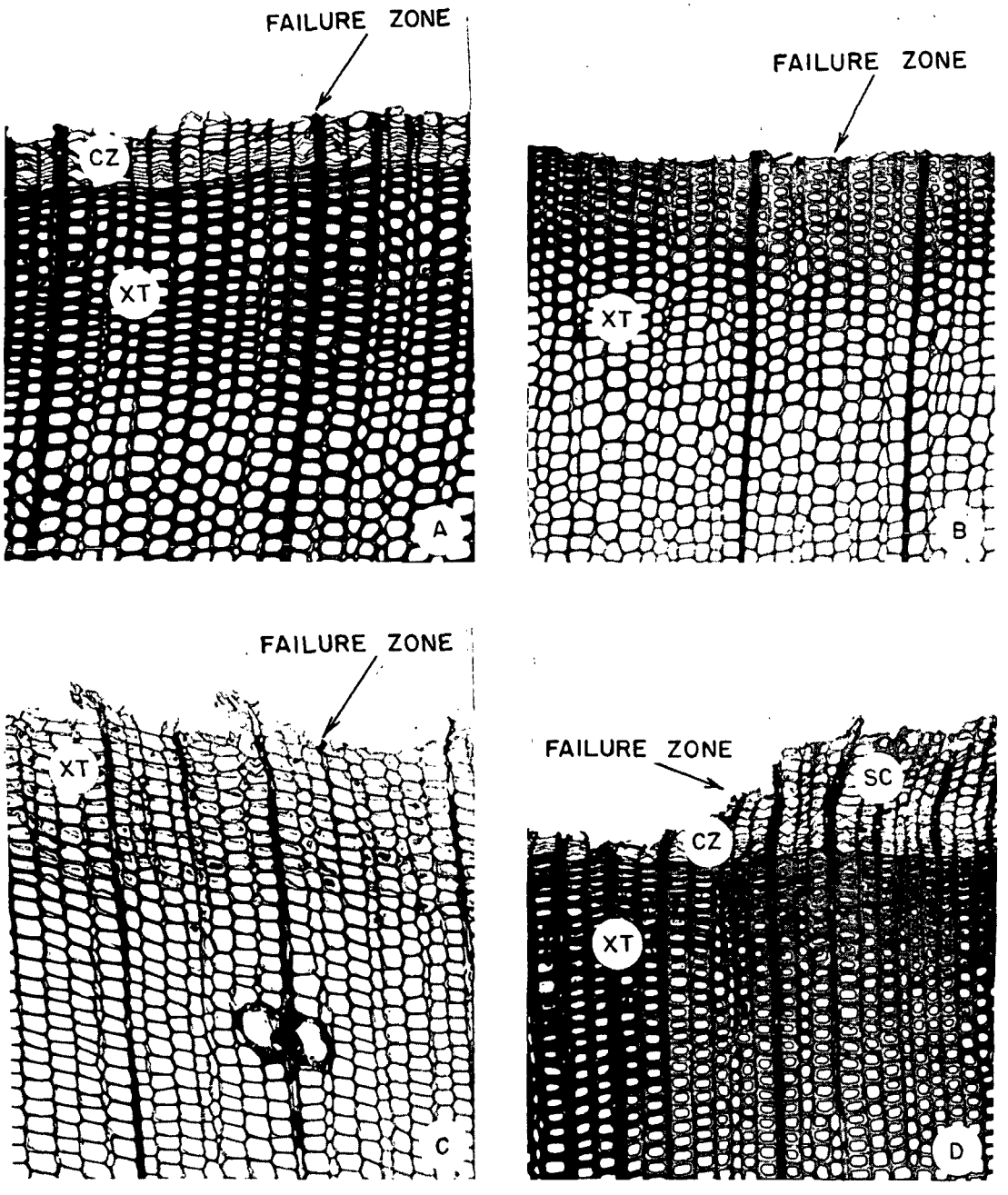

Figure 4. Illustrated are the Seasonal Changes in the Location of the Zone of Failure in White Spruce; A — March 29 Collection, Failure in the Inner Bark Area of Phloem Sieve and/or Parenchyma Cells Just Outside the Cambium Zone (CZ); B — May 10 Collection, Failure in the Cambium Zone (CZ) Between the Cambium Initials and the Fully Mature Previous Season Xylem Tracheids (XT); C — July 26 Collection, Failure in the Xylem Between the Xylem Initials and the Adjacent Immature Tracheids (XT); D — September 7 Collection, Failure Occurred in the Sieve Cells (SC) of the Inner Bark, Starting Near the Cambium Zone (CZ) and Going as much as 0.5 mm into the Inner Bark

bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids and a lack of phloem fibers seem to be associated with low dormant season wood/bark adhesion and low bark strength.

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips). Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

Erickson (16) reported 13 and 16% bark in fresh bolewood and topwood chips, respectively, for white spruce (mean of 14 samples). The percent of bark separated from wood during chipping of fresh bolewood varied from 35.7% in November to 98.7% in May. For fresh topwood the worst month again was November with 36.6% separation and the best month was May with 95.9% separation. Use of a ring debarker (17) works fairly well on white spruce with a ranking of 4* from early spring to late fall and 1-3* in winter using steam or a hot pond.

As discussed previously, several approaches that might have some promise were tried with hardwoods and two softwoods in Project 2929 to reduce adhesion. These methods included chemical, thermal and biological methods. White spruce was investigated in this study and was found to respond best of the six species studied to the methods used in terms of ease of adhesion reduction. White spruce, because of thin bark and low wood and bark specific gravity, does not separate

*Ranking system of 1 — easy to debark to 10 — hard to debark.

entirely satisfactorily as a result of the mechanical action of a chipper but demonstrated considerable reduction in wood/bark adhesion as a result of chemical and thermal methods. These methods are discussed in greater detail in the section on Between-Species Comparisons.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table IV summarizes the bark strength and toughness tests made on the wood and bark of white spruce. Table XXV under Between-Species Comparisons compares strength and toughness values for white spruce with other species investigated.

TABLE IV

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF WHITE SPRUCE[a]

Material	Strength	Toughness
Wood	--	0.34
Inner Bark	--	--
Outer Bark	7.4	0.16

[a]Determinations average of two different trees.

Strength and toughness tests were not able to be run on the inner bark of white spruce because of its extreme thinness. The outer bark strength value was moderate compared to other species investigated thus far (Appendix Table XXIX). Differences between wood and outer bark toughness were relatively small, indicating hammermilling or a similar technique might not work well on this species.

Summarized in Table V are the results of the hammermilling tests run on white spruce wood and bark. Hammermilling, followed by screening, can be expected to result in only a very modest reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled, and the material on the 14-mesh screen retained, the result was a 4% loss in wood and a 23% reduction in bark. The 23% reduction in bark is the lowest of any of the species tested thus far but the wood loss is also among the lowest. These results confirm conclusions drawn from the bark toughness test. Figure 5 illustrates the effect of hammermilling on wood and bark of white spruce. It is possible that a quick separation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions remaining high in bark could be treated by some other method. It is also possible that improvements

TABLE V

SUMMARY OF HAMMERMILLING TEST ON WHITE SPRUCE

Tree No.	Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-6	Bark	30	33	13	6	6	11	Inner bark very thin layer and seems to stay attached to outer bark.
	Sapwood	72	20	4	1	<1	1	
	Heartwood	64	27	4	2	1	1	
3212-35	Bark	40	31	11	5	5	8	Inner bark very thin layer and seems to stay attached to outer bark
	Sapwood	61	31	4	2	1	1	
	Heartwood	59	32	4	2	1	1	

[a] Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28 mesh screen has 28 wires per inch and an opening of 0.589 mm.

could be made in screening by taking advantage of the differences in configuration of wood and bark chips evident in Fig. 5 (18, 19).

WATER-FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is also expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

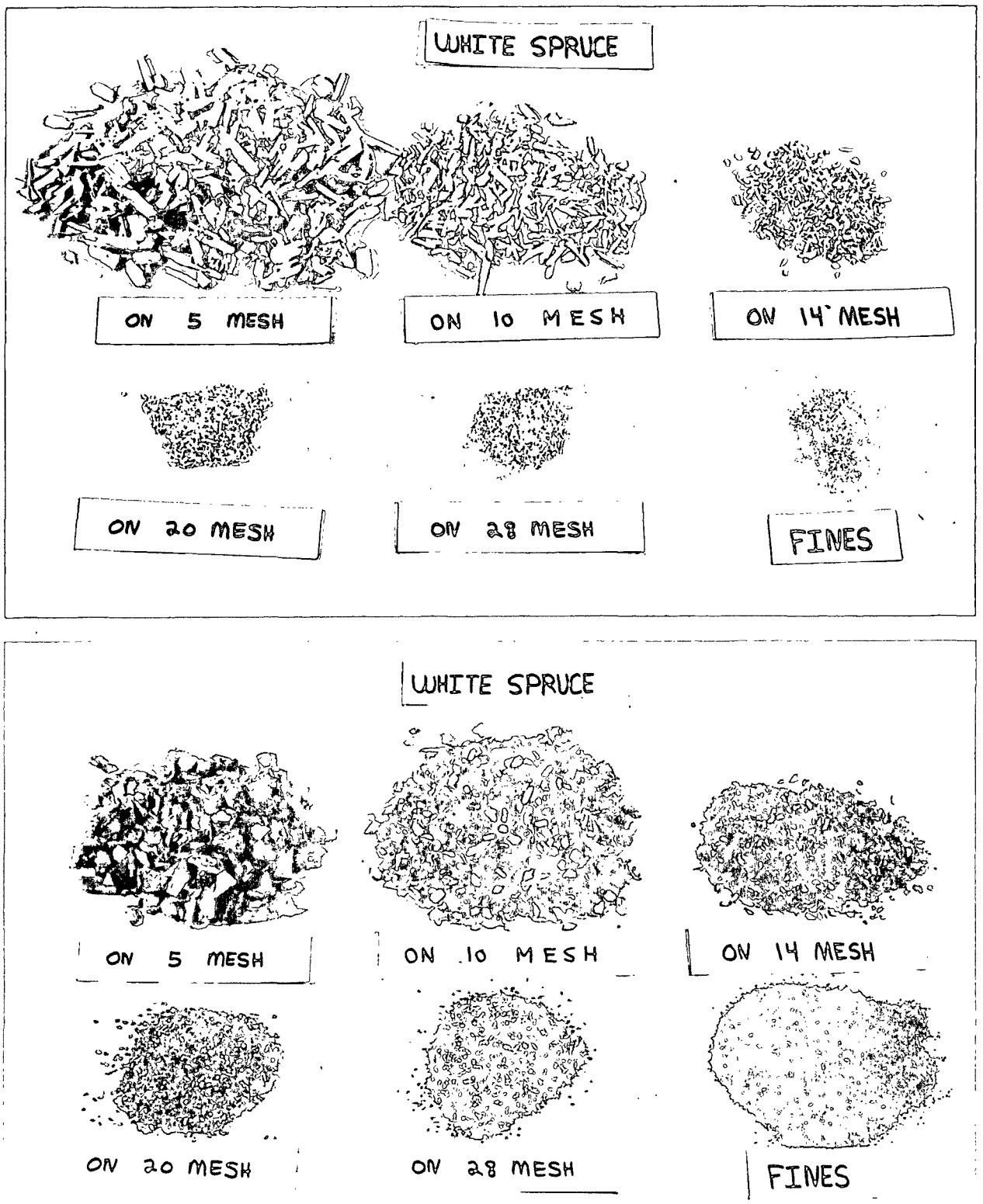

Figure 5. Illustrated is the Effect of Hammermilling on White Spruce Wood (Top) and Bark (Bottom)

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two white spruce trees (IPC 3212-6 and IPC 3212-35) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Since the inner bark of white spruce is so thin, only a very few density determinations could be made. These very few inner bark chips appeared to have approximately the same density as the outer bark. It also appeared that in a majority of cases the inner and outer bark would behave similarly to total bark under flotation conditions.

Figure 6 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in the terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

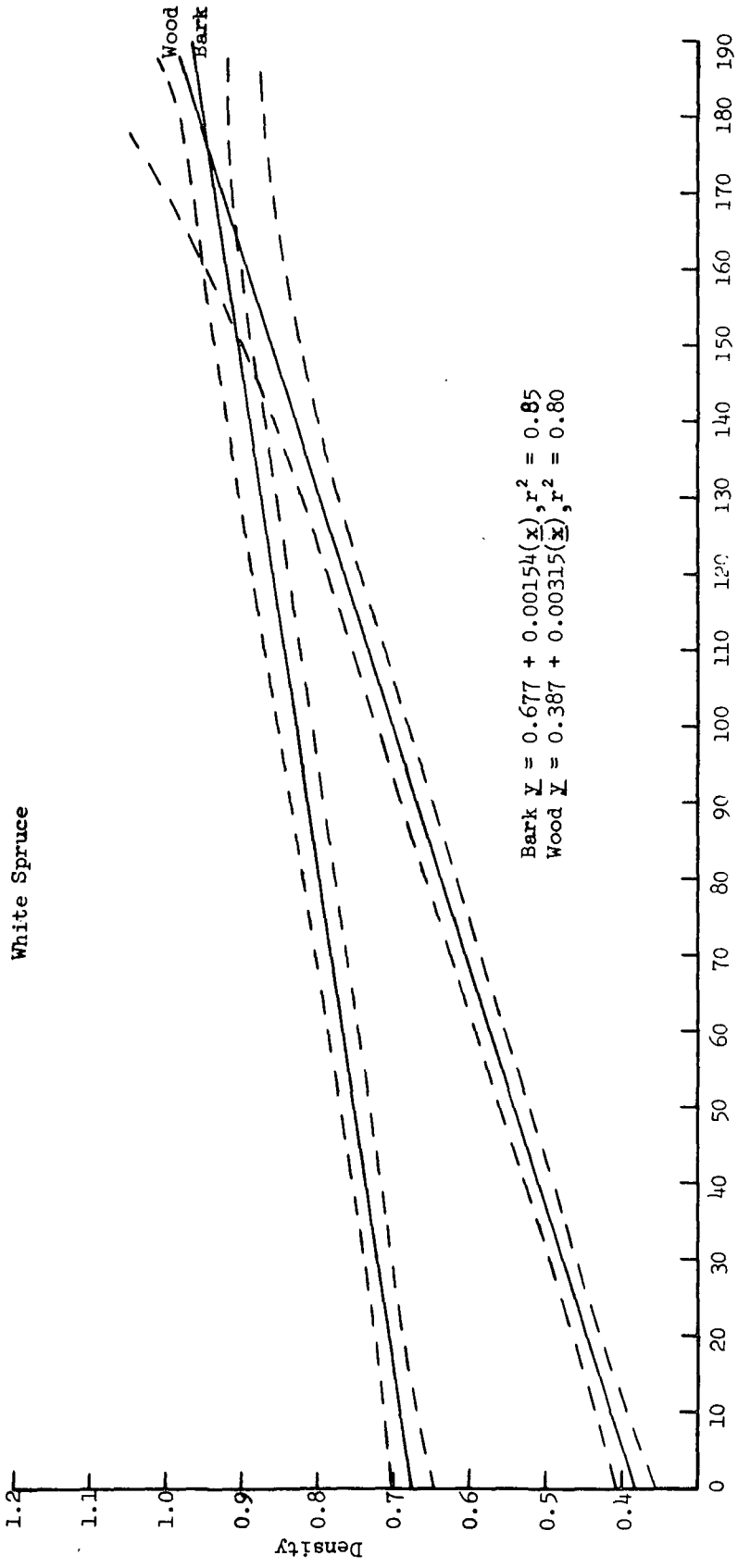

Figure 6. Illustrated is the Relationship Between Basic Density and Moisture Content for White Spruce. The Dashed Lines are Two Standard Deviations Above and Below the Mean

least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water-flotation studies, because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that segregation through water flotation would be difficult to achieve. Both wood and bark chips could be expected to float (density less than 1) even at very high moisture contents. However, several studies have shown that white spruce bark appears to take up water faster than the wood and this would be a favorable factor in water flotation. Work done previously in Project 2977 showed that a pitch glaze on the bark tended to inhibit water uptake and ultimate sinking of bark chips. This problem was solved by repeated compression between steel rollers over a 30-hour period, after which wood recovery was approximately 96% with 1.7-2.3% bark contamination. Robins (20) felt that a pressure system using 60 psig would possibly cause bark to sink while the wood remained floating although he did not test chips at this pressure. Julien, et al. (21) reported that at equal moisture contents the density of white spruce bark chips was greater than that of corresponding wood chips. This was also found to be true in our density determinations (Fig. 6) up to moisture contents of approximately 170%. They also tested wood and bark chips through water flotation in "as-cut," "air-dried" and "oven-dried" states. The best separation in the "as-cut" sample was obtained after 48 hours with 10% of the wood and 94% of the bark sinking. This time period was also best for the

"air-dried" sample with 3% of the wood and 84% of the bark sinking. The "oven-dried" sample required 72 hours for best segregation with 1% of the wood and 97% of the bark sinking.

It appears that in the case of white spruce, segregation through water flotation can be achieved but the long time periods required make the system somewhat impractical. Also, the wet rejects would be less useful as fuel.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar, and moisture uptake is similar, considerable difficulty in segregation can be anticipated. Time required for chip samples to sink decreases as the sample moisture content at the start of the trial increases.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table VI summarizes the results for white spruce. Substantiating our dwell time studies, Julien, et al. (21) reported 0% wood and 2% bark sinking after 4 hours in their "air-dried" samples.

TABLE VI

SUMMARY OF DWELL TIME RESULTS FOR WHITE SPRUCE[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-6 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-6 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-6 Heartwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-35 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-35 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-35 Heartwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

DATA INTERPRETATION

The bark of white spruce, thin in nature, contains no true fiber and a minor amount of sclereids, scattered in small groups. Estimates made on macerated samples indicate sclereids make up only 2-4% of the total bark weight.

Micropulping white spruce bark, followed by examination of the material retained on the 60- and 100-mesh screens, indicates that for every 100 grams of bark pulped, about 7 grams of sieve cells and 1.5 grams of sclereids will be produced. The sieve cells could be used as filler material in paper but probably would not contribute in any useful way to paper properties. However, because of the small numbers of sclereids and thin nature of the bark, this species ranks as one of the best prospects for pulping with the wood.

Because of the thin bark and low wood and bark specific gravity, separation of wood and bark through chipping was not entirely satisfactory, particularly during the dormant season. However, considerable reduction in adhesion appears possible using chemical or thermal methods. This species responded the best of any tested to separation of wood and bark through use of a green kraft cooking liquor at 200°F and also to pressure chamber treatments.

It appears that segregation through water flotation is possible because, although the densities of both wood and bark are less than that of water at high moisture contents, the bark seems to take up water faster than the wood. However, relatively long time periods would be required (at least 48 hours) and the wet rejects would be less useful as fuel.

Hammermilling, followed by screening, resulted in only a 23% reduction in bark but also only a 4% wood loss. It is possible that a quick separation could be made by screening, hammermilling the fractions high in bark and re-screening. It is also possible that improvements could be made in screening by taking advantage of the configuration differences between wood and bark.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating wood/bark chip mixtures. They include papers by Auchter and Horn (22), Sturos (23), Hooper (24), and Arola (25). A paper by Keays (26) gives a comprehensive study on complete-tree utilization while one by Hyland (27) gives an analysis of leaves, juvenile stems and roots. An additional paper is one by Hale (28) which gives information on bark thickness.

BARK AND WOOD PROPERTIES OF BALSAM FIR
[Abies balsamea (L.) Mill.]

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Balsam fir is found in extensive stands in the Boreal and northern forest regions of North America. In Canada, its range extends from Labrador, Newfoundland and Nova Scotia westward and north to the Athabaska River in Alberta. In the United States it ranges from northern Minnesota and Wisconsin eastward through the New England States and locally is found in Virginia, West Virginia and northeastern Iowa. Growing best in a cool moist climate, balsam fir reaches its best development in southeastern Canada and northeastern United States.

Growth of balsam fir, a member of the pine family and one of the most symmetrical of the northeastern conifer species, has been related to vigor and crown ratio (proportion of total tree height in live crown). Vigorous trees with adequate room will reach heights of 50-60 ft in about 50 years. Growth occurs from sea level to timberline at about 5,600 ft and is best on moderately deep sandy loam soils, well drained but abundantly moist. On average sites, the mature tree reaches a height of 40-60 ft with diameters, dbh, of 12-18 inches. The maximum size reported is a height of 75 ft and diameter of 34 inches. Maximum age is about 200 years. Common in balsam fir stands are several serious decay-causing fungi. These rots may occur as early as the 40th year and by 70 years, generally, more than half of the population is infected.

WOOD AND BARK MORPHOLOGY

Wood

Indistinguishable from the wood of other true firs, balsam fir is soft, light, medium-textured and straight-grained. The sapwood is creamy white composed of bands of light-colored earlywood and darker, lavender-tinged, bands of latewood. With distinct but not conspicuous growth rings, the springwood usually occupies two-thirds or more of the annual ring with a very gradual transition to latewood. Rays are very fine and normal resin canals are absent but traumatic (wound) canals are sometimes present, appearing as dark streaks along the grain.

Tracheids and uniseriate rays compose the xylem of balsam fir. Tracheids average 30-40 μm in diameter and 3.5 mm in length occupying about 94.3% of the total wood volume (5). The uniseriate rays are variable in height, from 1-30+ cells, and consist usually wholly of ray parenchyma. Rarely, a row of ray tracheids appear on the upper or lower margins of a ray.

Bark

On young trees and the upper part of old trees, balsam fir bark is dull green with greyish patches and smooth except for numerous raised resin blisters. With age, the bark breaks up into small reddish-brown, irregular thin scales and the blisters usually become dried. Comparatively thin, trees at age 30 usually have a bark thickness of 0.2-0.3 inch at breast height (1). Trees grown in favorable conditions or of greater age may have barks up to 0.5 or more inch thick. In cross section, the smooth outer bark of average age trees usually has one layer of light yellowish-brown periderm or cork, a cortical region with pronounced blister pockets and a broad secondary phloem region occupying about 1/2 to 3/4 of the total bark thickness. Due to the

persistent cortex and continuously developing periderm, rhytidome may not form until the tree is very old and/or only at the basal portion of the trunk. In the trees used in this study, the inner bark ranged from approximately 70% to 85% of the total bark thickness by weight. Figure 7 illustrates a cross section of balsam fir wood and bark. Appendix Table XXVII describes the trees used in this study.

Anatomical Structure of Mature Bark

Balsam fir bark, of approximately 30-year-old trees, is composed of the same three regions, periderm, cortex, and secondary phloem, as a young stem. Differences are only in the proportional widths of the zones and the increase in sclereids or lignified cells with age. The periderm consists of one layer of phellogen, 2-3 layers of regularly aligned and generally compact phelloderm which merges with the cortex, and variable layers of thin-walled phellem or cork cells. The broadest region in young branches and stems, the cortex is composed of parenchyma type cells aligned rather regularly in more or less tangential lines at the outer margin. Some cells become enlarged and, as the tree ages, some become lignified and form small sclereid groups. In the middle of the cortex of the young tree are always 1 or 2 layers of resin canals that later enlarge to form the "blister pockets." They are aligned in more or less tangential rows and some open to the outer surface of the bark. The secondary phloem (inner bark) is the broadest zone with sclereid groups distributed sporadically and sometimes almost tangentially aligned in the mature tree.

The inner bark of balsam fir consists of radially aligned sieve cells and phloem rays interspersed with parenchyma, resin passages and sclereid groups. Sieve cells, rectangular in cross section and varying from 20-35 μm and 10-30 μm in tangential and radial dimensions, respectively, have an average

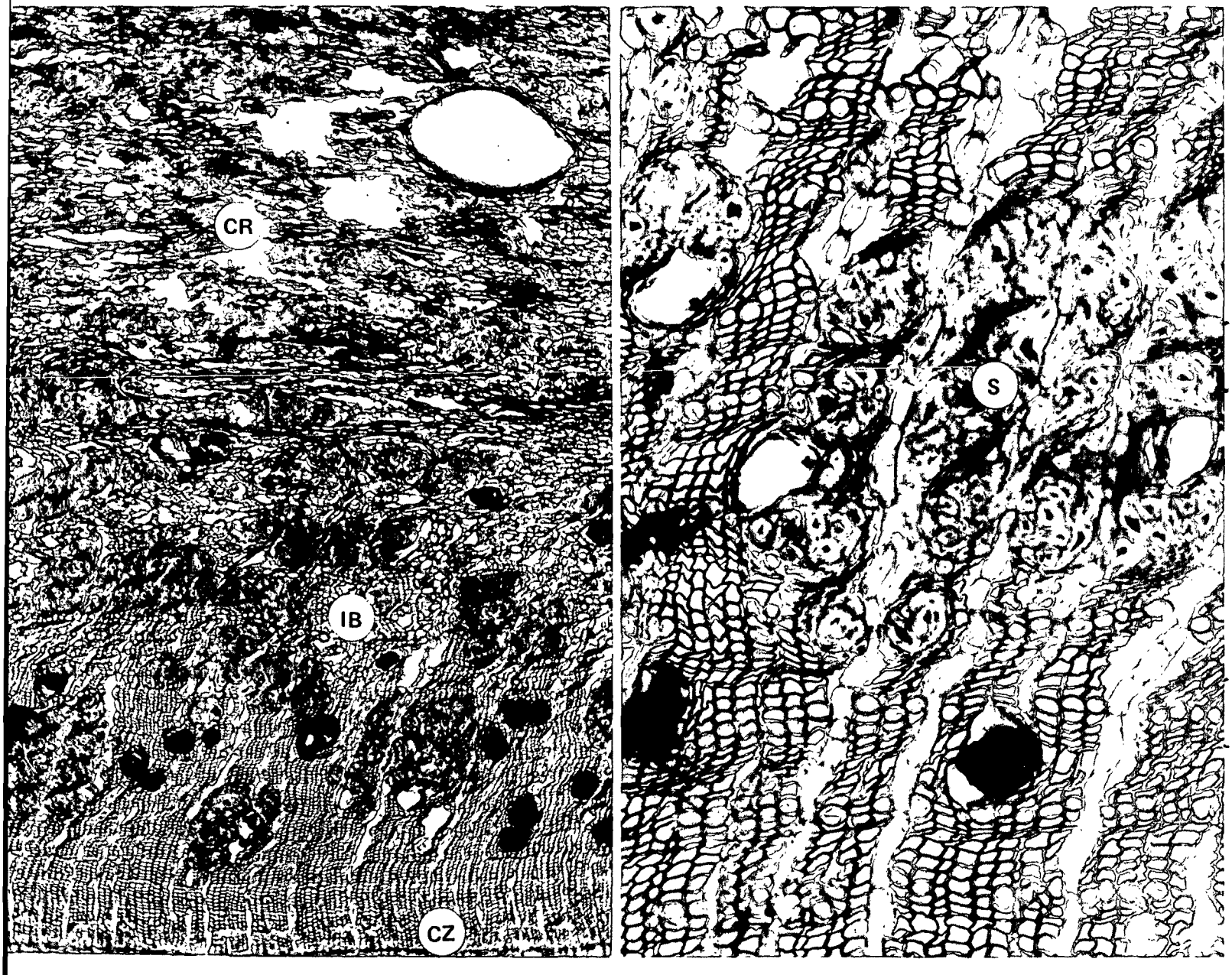

Figure 7. Cross Section of Balsam Fir. Photomicrograph on the Left Shows Cambium Zone (CZ), Inner Bark (IB) and Cortical Region (CR). Note the Proximity of the Sclereid Groups (S) to the Cambium Zone. Photomicrograph on the Right is a Cross Section of the Inner Bark Showing the Arrangement of the Sieve Cells, Phloem Parenchyma, Phloem Rays and Sclereid Groups (S). The Large Porelike Spaces and Dark Areas are the Resin Passages. Magnification — 35X Left, 75X Right

length of 1.5-2.2 mm (1). Usually 5-9 cells are aligned between two more or less tangential rows of parenchyma. Phloem parenchyma usually appear in single layers but are sometimes sporadic. A strand is generally about the same length as the adjacent sieve cells. The thin-walled parenchyma cells, containing a tanniferous substance and single calcium oxalate crystals, are approximately the same as the sieve cells on cross section but often radially expanded. Parenchyma and ray cells are the origin of the phloem sclereids. Cell walls become "lignified" and very thick and individual cells often lose their original shape, becoming branched and twisted and forming groups of often 20 or more. Phloem rays, generally uniseriate, are usually 10-20 cells or 200-300 μm high. Erect ray marginal or albuminous cells, in single or occasionally double rows, are present on rays close to the cambial zone. From these cells, the resin cells originate. "Resinous" droplets in the protoplasm disintegrate the cell nucleus, and, as the content increases, obliterate the original protoplasm, burst the cell wall and form a new resin passage. As the resin flows through, adjacent phloem tissues are also often obliterated and the cell walls broken. These resin passages, vertical or irregular, are without border cells. As the tree ages, sieve cells at the outer part of the inner bark become obliterated or lignified and resin passages and sclereid groups increase in the secondary phloem and often appear in the late-formed rhytidome of the balsam fir.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and sclereids are expected to be useful in determining the need

and possible methods of separating and segregating wood/bark chip mixtures*. Whenever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table VII summarizes the information available on wood and bark of balsam fir and, whenever possible, information on bark has been separated into inner and outer bark. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. It should be noted that several of the values in Table VII are ovendry weights divided by ovendry volumes. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report under the section Water Flotation Behavior compares the basic density (green weight divided by green volume) of balsam fir at several moisture contents.

An average specific gravity (ovendry weight/green volume) of approximately 0.34 appears appropriate for the wood of balsam fir. Our limited data do not show much of a difference between heartwood and sapwood.

The specific gravity of the total (inner + outer) bark of balsam fir appears fairly close to that of the wood or perhaps slightly higher. Our limited data show the inner bark to be lower in specific gravity than the outer bark. Overall values suggested for use in species comparisons are 0.34 for wood and 0.32, 0.46 and 0.40 for inner, outer, and total bark.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

TABLE VII

BALSAM FIR SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood		Bark				Reference and Remarks
Average	Range	Inner	Outer	Total	Range	
0.34	0.31-0.38 (tree)					Maeglin (3)
0.32	0.27-0.40 (core)					Maeglin (3)
0.35	Diam. class 8.0-9.8					Maeglin (3)
0.34						Isenberg (5)
0.32	0.29-0.35			0.37	0.28-0.44	Erickson (6)
				0.50[a]		Millikin (4)
0.30 (Last-formed sapwood)		0.32	0.42	0.38		Lamb & Marden (29)
		0.32	0.42	0.38		Fournier & Goulet (7)
0.34	0.31-0.36 (Diam. class 7.6-8.9)					Pronin (8)
0.34	0.27-0.49 (Diam. class 4.6-8.9)					Wahlgren, et al. (9)
0.32	0.28-0.36			0.34		Besley (Canada) (10)
0.34				0.33		Besley (U.S.) (10)
0.35 (Sapwood) 0.36 (Heartwood)		0.34	0.50	0.45		IPC 3212-13
0.38 (Sapwood) 0.36 (Heartwood)		0.31	0.51	0.47		IPC 3212-14
				0.63[b]		Harkin & Rowe (11)
0.37[b]						Isenberg (5)
0.38[b]	0.34-0.42			0.71[b]	0.66-0.78	Erickson (6)

[a] Rough estimate based on conversion from lb OD bark per cu ft.
[b] Ovendry weight/ovendry volume.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

A range in levels of extractives in wood from 1.4% to 2.9% has been reported for balsam fir (see Table VIII). For btween-species comparisons, an extractives level of 2.0% is suggested for the wood of balsam fir. Based upon information obtained from the two trees sampled as part of this project, the bark of balsam fir can be expected to have an extractives level of 19.5%. This relatively high level of extractives might cause problems in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other techniques.

TABLE VIII

BALSAM FIR ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	2.2-2.9	Rydholm (13)
Wood	1.4	Isenberg (5)
Bark	16.5	Harkin & Rowe (11)
Bark	21.2	IPC 3212-13
Bark	20.8	IPC 3212-14

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product. The principal elements in the bark of balsam fir having an effect on the pulp are sclereids and sieve cells. There are no true fibers in the bark of balsam fir.

The short, thin-walled sieve cells (see photomicrographs) could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve cells, would probably be extremely brittle and low in strength. Sieve cells could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of this problem.

Sclereids are short, thick, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. Estimates made of IPC macerated bark samples suggest that sclereids make up 20-23% of the total bark weight. According to Chang (1), 8.2% of the tissue elements in the inner bark are sclereids based upon examination of cross sections. IPC measurements indicate sclereids would be more of a problem than might be indicated by Chang's data. Lamb and Marden (29) reported that sclereids were found in both large

and small scattered groups in the inner bark. These sclereids are mainly branched and thick-walled and of the type that causes problems in high-yield pulping.

As a check on pulp yield and the nature of the material produced from balsam fir, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micro-pulping Procedure. Table IX summarizes the results of this investigation. Micro-pulping balsam fir bark resulted in a yield of 23 to 29% solids. When screened, the coarse screens (60 and 100 mesh) retained approximately half the sclereids and most of the sieve cells. The on 150-mesh screen contained mainly groups of branched, thick-walled sclereids. The on 200-mesh and through 200-mesh screens also had a high percentage of sclereids. Figure 8 illustrates the type of material on the 60- and 150-mesh screens.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 26 grams of solids will result. Of this 26 grams, about 2 grams (2%) of sieve cells and 12 grams (12%) of sclereids will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations. The amount of sclereids remaining is the highest of any species investigated so far and indicates removal of the bark would probably be desirable in most instances.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species.

TABLE IX

BALSAM FIR MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-13	Sample No. 3212-14	Remarks[a]
Yield, % solids	23.2	28.8	
Fraction			
On 60 mesh, %	27.5	403.	The furnish contained principally groups of branched thick-walled sclereids (80-90%) and a smaller percentage of sieve cells (10-20%). The length of the sieve cells contained in the fraction was: (1) Arithmetic ac. length — 1.43 mm, (2) weighted av. length — 1.62 mm
On 100 mesh, %	21.6	16.8	The furnish of the fraction also contained principally groups of branched, thick-walled sclereids (80-90%) and a smaller percentage of sieve cells (10-20%)
On 150 mesh, %	13.0	10.3	The furnish contained principally groups of branched thick-walled sclereids (95+%) with a small percentage of sieve cells (< 5%) and a trace of parenchymatous cells (< 1%)
On 200 mesh, %	7.2	5.4	Same furnish as reported for the "On 150" fraction
Through 200 mesh, %	30.7	27.2	The fraction furnish contained a large percentage of individual sclereid cells (70-80%) with a smaller percentage of parenchymatous cells (20-30%) and a trace of sieve cells (< 1%)

[a]Percentages given are on a dry weight basis.

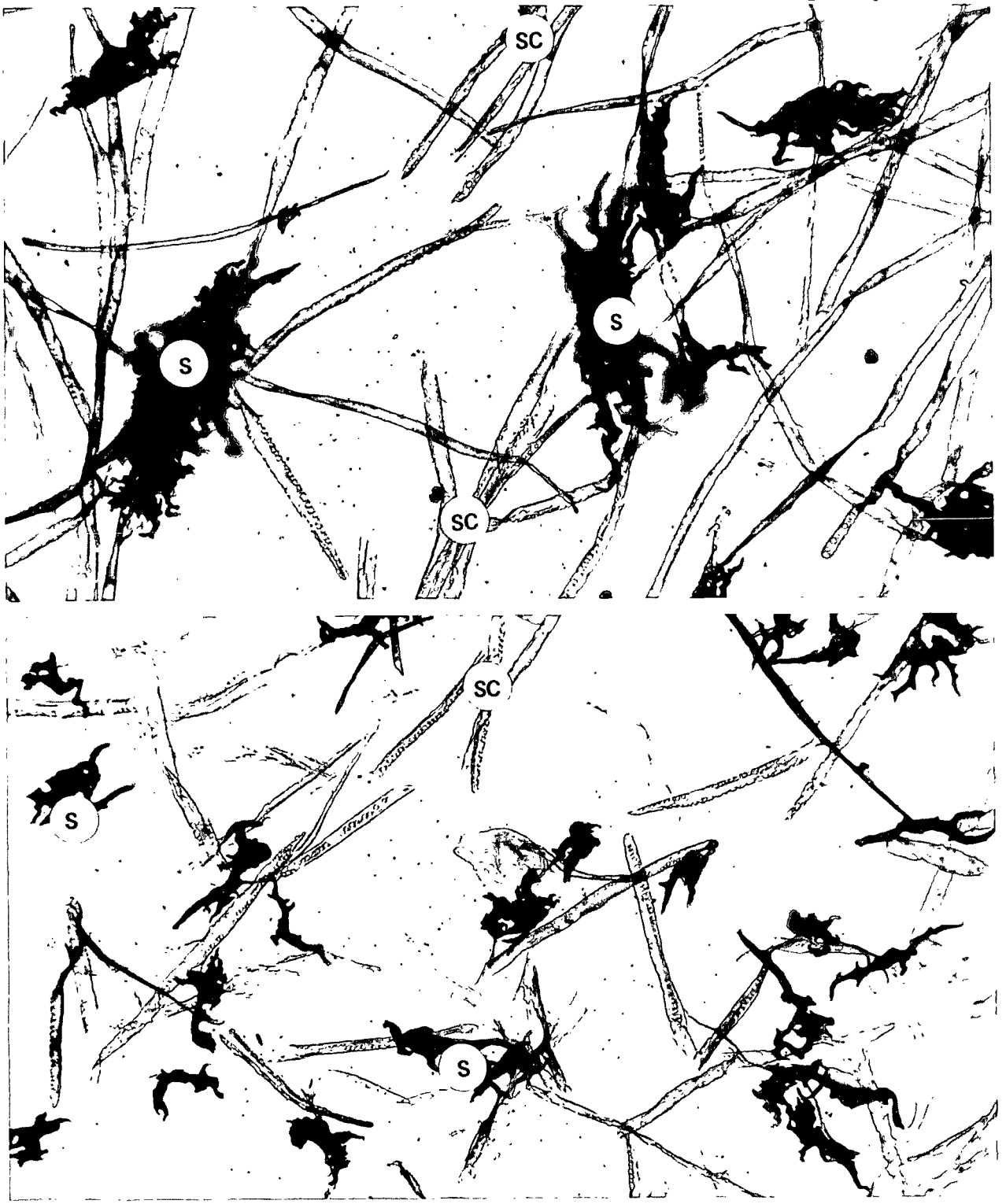

Figure 8. The 60-Mesh Screen (Top) Contained by Weight Principally Groups of Branched, Thick-Walled Sclereids (80-90%) and a Smaller Percentage of Sieve Cells (10-20%). The 150-Mesh Screen (Bottom) Contained Primarily Groups of Branched, Thick-Walled Sclereids (95+%) and Some Sieve Cells (< 5%). Magnification — 75X. Symbols Include Sclereids (S), and Sieve Cells (SC)

The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Wood/bark adhesion values were measured for balsam fir samples collected July 17 (growing season) and December 3 (dormant season). Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured. After testing, the samples were examined to determine the location of the zone of failure. Figure 9 illustrates the zone of failure for balsam fir during both the growing and dormant seasons. During the growing season, wood/bark adhesion was low (2.4 kg/cm^2) and the failure zone was located between immature xylary initials in the proximity of the cambium zone. Secondary wall thickening was still in process and all cells in the last-formed growth ring were earlywood. During the dormant season, wood/bark adhesion increased to 9.0 kg/cm^2 and the failure zone was found to be primarily between cells in the cambium zone located approximately 3-4 cells from the fully mature xylem tracheids. One small corner of the break extended approximately 0.5 mm into the phloem in a jagged radial line along sieve and phloem ray cells.

Again, it is noted that sclereids are abundant in balsam fir and appear within 0.5-1 mm from the cambium zone. Possibly in some specimen samples collected early in the year (January, February, March) before new growth begins or even in other samples collected after seasonal growth ceases, the failure zone may occur in the inner bark and include groups of sclereids. These type cells are, of course, responsible for the translucent spots (fisheyes) which may show up in some grades of paper.

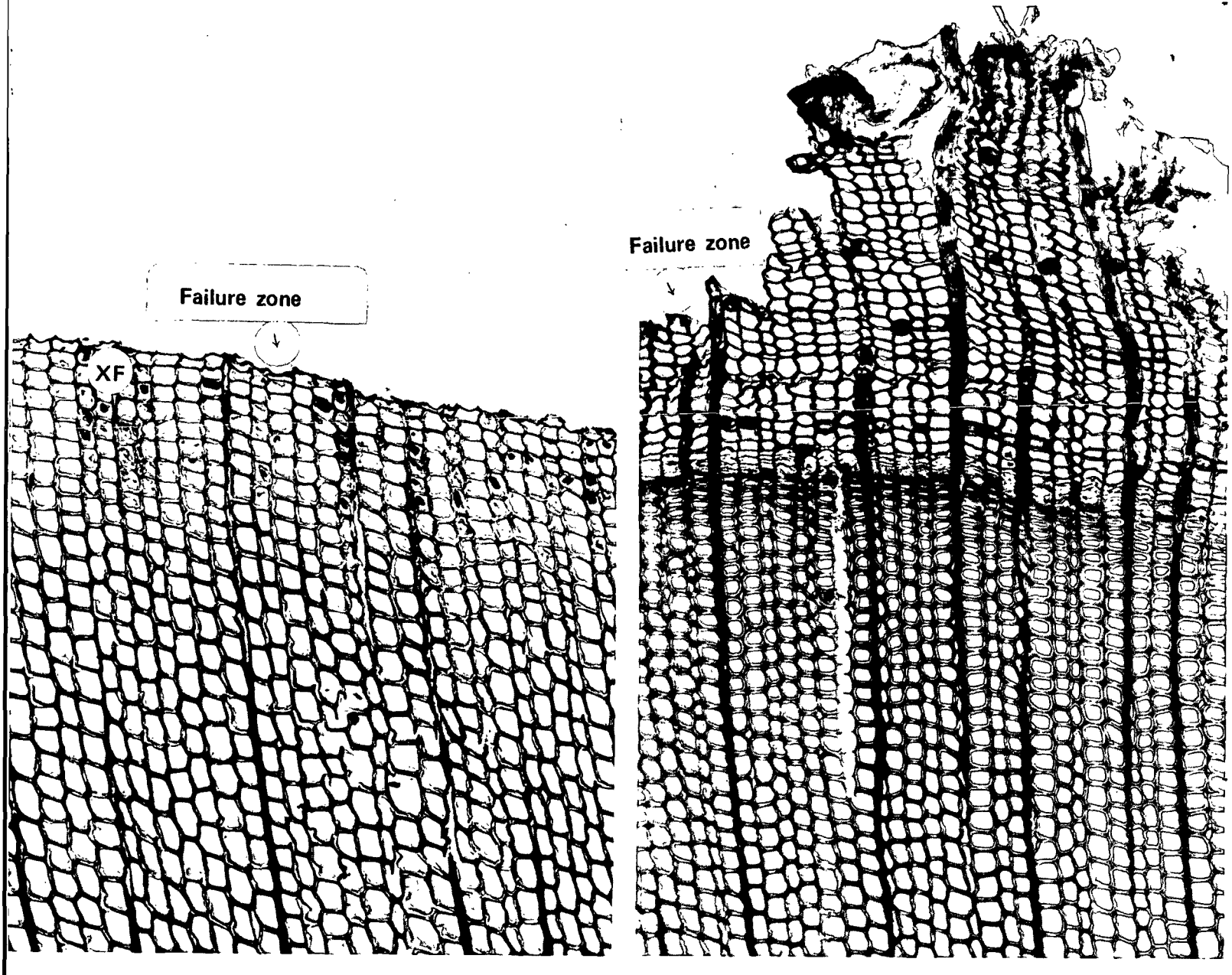

Figure 9. Illustrated is the Balsam Fir Failure Zone for Both the Growing Season (Left) and Dormant Season (Right). The Growing Season Failure Zone was Located Between Immature Newly-Formed Xylem Fibers (XF) in the Proximity of the Cambium Zone. During the Dormant Season, the Failure Zone was Located Between Cells in the Cambium Zone (CZ) Approximately 3-4 Cells from the Fully Mature Xylem Tracheids. One Small Corner of the Break Extended Approximately 0.5 mm into the Phloem in a Jagged Radial Line Along Sieve and Phloem Ray Cells. Magnification — 125X

As a result of measurement data taken on the species included in Appendix Table XXVIII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids and a lack of phloem fibers seem to be associated with low dormant season wood/bark adhesion and low bark strength.

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips). Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

Erickson (16) reported 14 and 17% bark in fresh bolewood and topwood chips, respectively, for balsam fir (mean of 14 samples). The percent of bark separated from wood during chipping of fresh bolewood varied from 53.8% in November to 99.8% in May. For fresh topwood the worst month again was November with 48.0% separation and the best month was May with 99.5% separation.

As discussed previously, several of the approaches that were tried with hardwoods in Project 2929 to reduce adhesion might have some promise with softwoods. They included chemical, thermal and biological methods. These methods have not been tried with balsam fir but are worthy of further consideration and are discussed in greater detail in the section on Between-Species Comparisons.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficuty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table X summarizes the bark strength and toughness tests made on the wood and bark of balsam fir.

Relatively small differences were obtained in bark strength between the inner and outer bark. A toughness test was not able to be run on the outer bark because of its thinness. However, the differences in toughness between the inner bark and the wood were quite large. In addition, these values were low, less than those obtained for many of the hardwoods and even a number of the softwoods. This is probably due to the lack of fiber in balsam fir bark. Appendix Table XXIX summarizes the bark strength values for balsam fir and includes a number of other species for comparison purposes.

TABLE X

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF BALSAM FIR[a]

Material	Strength	Toughness
Wood	--	0.42
Inner Bark	1.7	0.06
Outer Bark	1.4	--

[a]Determinations average of two different trees.

Summarized in Table XI are the results of the hammermilling tests run on balsam fir wood and bark. Hammermilling, followed by screening, worked better on this species than on any investigated so far. When the half-sized chips for the two trees investigated were hammermilled, and the material on the 14-mesh screen retained, the result was a 6% loss in wood and a 44% reduction in bark. Figure 10 illustrates the effect of hammermilling on wood and bark of balsam fir. It is possible that further improvements could be made in screening by taking advantage of the differences in configuration of wood and bark chips evident in Fig. 10 (18, 19). Summary Table XXV compares bark strength, toughness and reaction to hammermilling of balsam fir to other species tested thus far.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is also expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood

TABLE XI

SUMMARY OF HAMMERMILLING TEST ON BALSAM FIR

Tree No.	Type Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-13	Bark	12	20	18	11	14	24	Appears to be half inner & outer bark on all screens except very finest which may have slightly higher percentage of inner bark
	Sapwood	59	29	6	3	2	2	
	Heartwood	50	37	7	2	1	2	
3212-14	Bark	14	30	17	11	10	18	Appears to be half inner & outer bark on all screens except very finest which may have slightly higher percentage of inner bark
	Sapwood	52	37	6	2	1	2	
	Heartwood	49	37	8	3	1	2	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28 mesh screen has 28 wires per inch and an opening of 0.589 mm.

chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chips size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

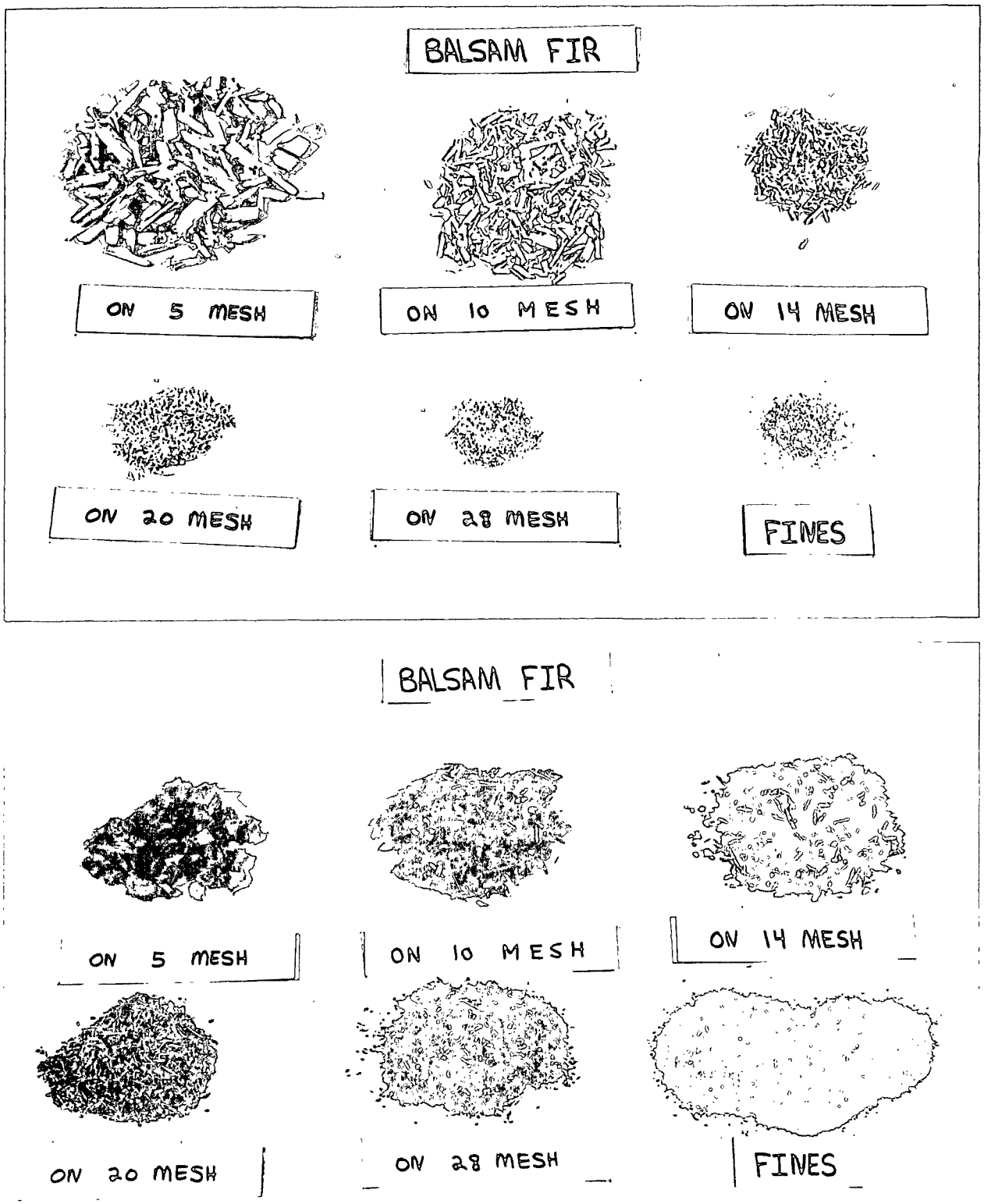

Figure 10. Illustrated is the Effect of Hammermilling on Balsam Fir Wood (Top) and Bark (Bottom)

Density Determinations

Simulated chips were used in determining the relationship between moisture content and the density of bark and wood. Wood and bark from two balsam fir trees (IPC 3212-13 and IPC 3212-14) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. The inner bark appeared to have approximately the same density as the outer bark and it appeared that in a majority of cases the inner and outer bark would behave similarly to total bark under flotation conditions.

Figure 11 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies, because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that at moisture contents of 100% or greater most bark chips could be expected to sink (density greater than 1). Balsam fir wood, on the other hand, could be expected to float at moisture contents of less than

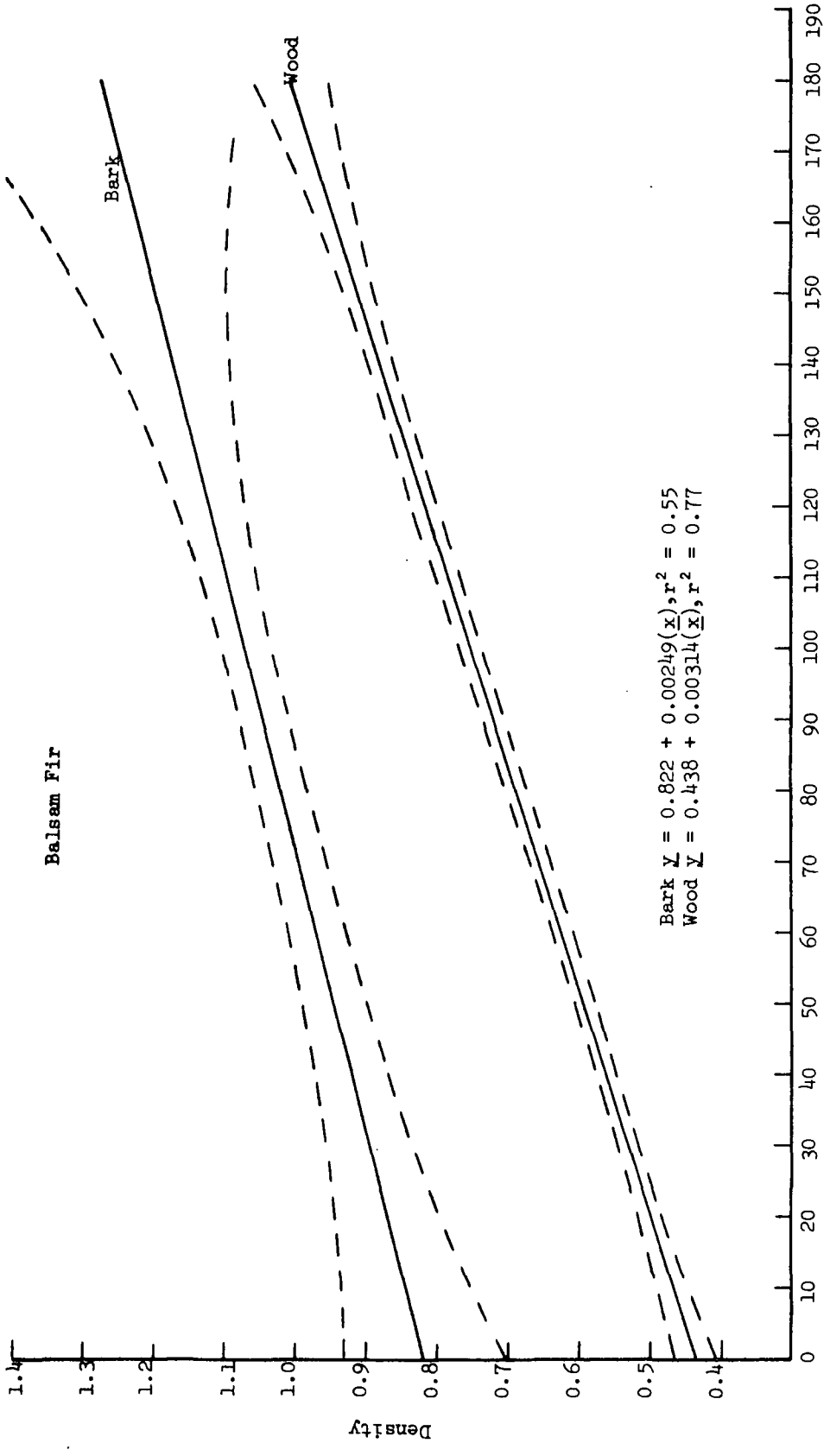

Figure 11. Illustrated is the Relationship Between Basic Density and Moisture Content for Balsam Fir. The Dashed Lines are Two Standard Deviations Above and Below the Mean

170% (density less than 1). Julien, et al. (21) reported that at equal moisture contents the density of balsam fir bark chips was greater than that of corresponding wood chips. This was also found to be true in our density determinations (Fig. 11). They also tested wood and bark chips through water flotation without pressure in "as-cut," "air-dried" and "oven-dried" states. No acceptable segregation was obtained in the "as-cut" samples with too high a percentage of wood sinking with the bark at all moisture contents. The best separation in the "air-dried" samples was obtained after 24 hours with 4% of the wood and 95% of the bark sinking. The best method appeared to be the flotation of "oven-dried" bark and wood. After 36 hours, no wood and 97% of the bark sank. Robins (20) reported no satisfactory segregation of balsam fir was possible at 40 psig. He felt that altering the water medium with a polymer might cause the wood to absorb less water and improve segregation results. Again, as is the case with white spruce, it appears segregation through water flotation could be achieved, but only after long time periods.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar, and moisture uptake is similar, considerable difficulty in segregation

can be anticipated. Time required for chip samples to sink decreases as the sample moisture content at the start of the trial increases.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table XII summarizes the results for balsam fir. These results are somewhat at variance with the results obtained by Julien, et al. (21) who reported no wood and 36% of the bark sinking after 4 hours with their "air-dried" samples (13 and 17% moisture content for wood and bark, respectively, at the start of the trial). Our results indicated longer dwell times would be required to effect any segregation.

DATA INTERPRETATION

Balsam fir is a "problem species" as far as the bark is concerned because it contains no true fiber and large numbers of sclereids. Estimates made on macerated samples indicate these thick, heavily lignified cells make up 20-23% of the total bark weight. This is the highest percentage of sclereids of any species investigated so far.

Micropulping of balsam fir bark, followed by examination of the material retained on the 60- and 100-mesh screens, indicates for every 100 grams of bark pulped, 2 grams of sieve cells and 12 grams of sclereids will be produced. This is about half of the total amount of sclereids found in the bark with the rest being lost in washing and cleaning operations.

Considering the lack of fiber and the presence of large numbers of sclereids, removal of at least part of the bark appears desirable. Separation of wood and bark through chipper action works well during the growing season but is much less successful during the dormant season.

TABLE XII

SUMMARY OF DWELL TIME RESULTS FOR BALSAM FIR[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-13 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-13 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-13 Heartwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-14 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-14 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-14 Heartwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

Segregation through water flotation also appears possible for balsam fir. In the best test reported in the literature, no oven-dried wood and 97% of the oven-dried bark sank after 36 hours. The drawbacks again are the long time periods required and the wet rejects which would be less useful as fuel.

The approach that appears worthy of the most consideration is the use of a "screening — hammermilling — screening" procedure. By screening the chips

first, concentrating the bark in smaller chip fractions, hammermilling those fractions and rescreening, it appears a considerable reduction could be made in bark contamination. In hammermilling trials run at the Institute, the result was a 6% loss in wood and a 44% reduction in bark. It is possible that further improvements could be made in screening by taking advantage of chip configuration.

RELATED LITERATURE

Again, a number of papers deal with the economics and mechanics of segregating wood/bark chip mixtures. They include previously cited papers by Auchter and Horn (22), Sturos (23) and Hooper (24) plus an additional paper by Sturos (30). The previously cited paper by Hyland (27) gives an analysis of leaves, juvenile stems and roots. An additional paper by Hale (28) gives information on bark thickness while one by Young (31) gives information on bark percentages and chemical elements in bark.

BARK AND WOOD PROPERTIES OF JACK PINE
(Pinus banksiana Lamb.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Jack pine, found farther north than any other American pine, is native to northern New England, the Lake States, and Canada. It is most abundant in central Michigan and Wisconsin, and on the sand dunes at the south end of Lake Michigan. The best development of this species probably occurs in the crescent-shaped area north of Lake Superior and Lake Huron. Jack pine, short-lived and small to medium-sized, averaging 60-70 ft tall and 10-20 inches in diameter, is able to endure an extremely cold climate. In general, the natural range is characterized by cool summers, very cold winters, low rainfall, light sandy soils and level to rolling topography.

WOOD AND BARK MORPHOLOGY

Wood

Jack pine wood, medium-textured and moderately heavy and soft, has wide, nearly white sapwood. Light orange-brown heartwood formation is usually delayed until the tree reaches the age of 40-50 years. Growth rings are distinct with an abrupt transition from earlywood to the darker and denser latewood. The earlywood zone is usually much wider although both are variable in width.

The xylem is composed of tracheids, uniseriate and fusiform rays, and longitudinal and transverse resin canals. Jack pine tracheids, radially aligned in distinct rows, average 27-37 μm in diameter and 3.5 mm in length (5). Uniseriate rays, usually 1-10+ cells in height, are numerous. Fusiform rays are scattered, usually with a transverse resin canal. Ray tracheids, shallowly dentate, are present in both types of rays. Ray parenchyma are slightly and

irregularly thickened. Smaller than in most pines, the horizontal resin canals have an average diameter of 33 μm, and the longitudinal canals, 75-90 μm.

Bark

Dull brown with a yellowish hue on the outer surface, the relatively thin jack pine bark forms small scales and narrow furrows. Narrow layers of pinkish-yellow periderm and deep reddish-brown secondary phloem with abundant resin canals appear in the outer bark. Inner bark is very narrow and about the same width as the rhytidome layers. In the trees used in this study, the outer bark ranged from approximately 80% to 95% of the total bark thickness by weight. Figure 12 illustrates a cross section of jack pine wood and bark. Appendix Table XXVII describes the trees used in this study.

Anatomical Structure of Mature Bark

The formation of the narrow and numerous rhytidome layers involves the expansion of parenchyma and ray cells in the inner and outer bark, and the development of the thin and alternately thick, heavily "lignified" phellem cells in the periderm. Rather broad, the periderm is composed of a layer of phellogen, alternate layers of thin and thick-walled phellem and 4-7 layers of phelloderm. Phellem and phelloderm cells, rectangular on cross section, are about the same size and shape, mostly 30-40 μm and about 20 μm on tangential and radial dimensions, respectively (1). Isolated by the successive periderm layers, the secondary phloem tissues in the rhytidome are in great contrast to those of the inner bark because of the expanded parenchyma, crushed sieve cells and numerous resin canals.

The inner bark (secondary phloem) of jack pine is composed of sieve cells, phloem parenchyma and both uniseriate and fusiform rays. Sclerenchyma

are absent. Sieve cells, radially aligned, are rectangular on cross section and variable in size, usually 15 ± 10 μm in radial diameter and 35 ± 15 μm in tangential diameter with an average length of 1.2-3.0 mm. Cell walls are cellulosic and appear to show distinct secondary wall thickenings. Interrupting every 11-19 cells in a radial row are single-layered lines of parenchyma. On cross section, parenchyma cells close to the cambial area are similar in size and shape to the adjacent sieve cells but they quickly expand and occupy most of the secondary phloem region. Individual cells are usually 70-150 μm in height and a parenchyma strand is about the same length as the neighboring sieve cells. Uniseriate rays are generally 10 cells or 200-300 μm in height with erect ray marginal, or albuminous cells, 2-3 times the height of regular ray cells, in all rays close to the cambium. Fusiform rays contain horizontal resin canals lined by 3-4 thin-walled epithelial cells.

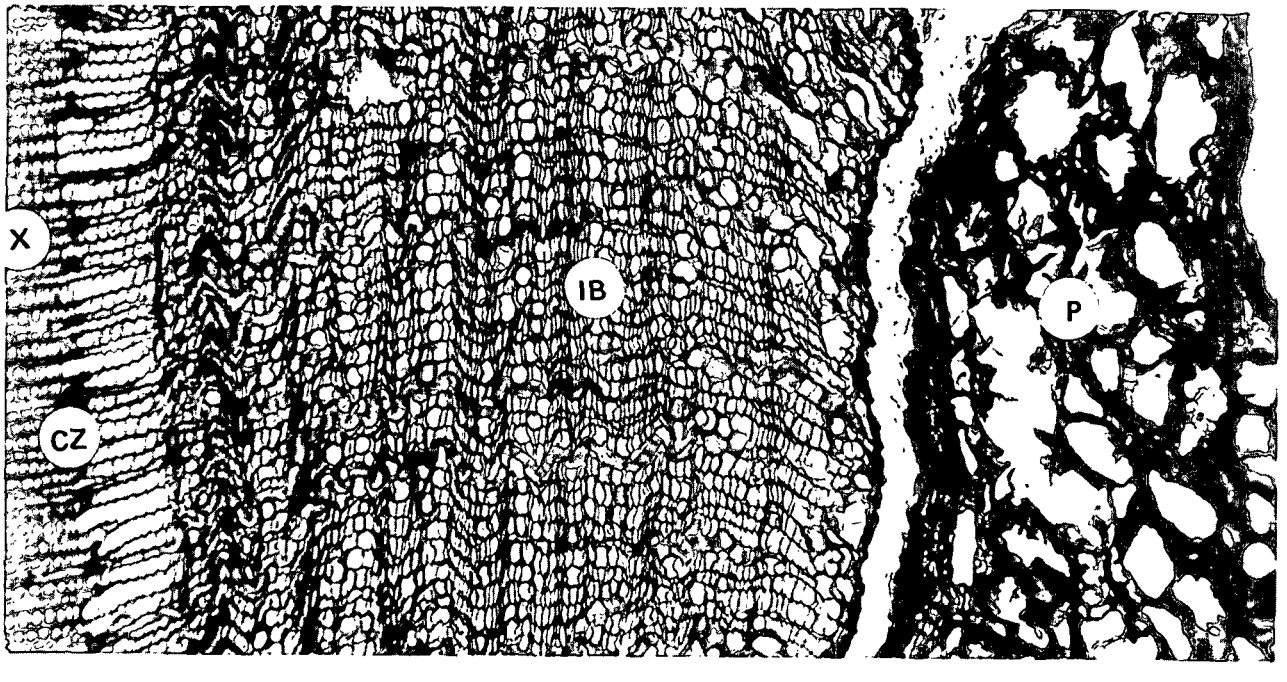

Figure 12. Cross Section of Jack Pine Showing Xylem (X), Cambium Zone (CZ), and Inner Bark (IB) Showing the Arrangement of Sieve Cells, Parenchyma and Phloem Rays (Note that the Last-Formed 6-8 Rows of Sieve Cells Adjacent to the Cambium Zone are Uncollapsed and Should not be Confused with the Cambium Zone). Also Shown is the Last-Formed Periderm (P) of the Outer Bark. Magnification — 75X

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and sclereids are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Whenever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table XIII summarizes the information available on wood and bark of jack pine. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. It should be noted that several of the values in Table XIII are ovendry weights divided by ovendry volumes. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report under the section Water Flotation Behavior compares the basic density (green weight divided by green volume) of jack pine at several moisture contents.

An average specific gravity (ovendry weight/green volume) of approximately 0.39 appears appropriate for the wood of jack pine. Our limited data do not show much of a difference between heartwood and sapwood.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

TABLE XIII

JACK PINE SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood		Bark				Reference and Remarks
Average	Range	Inner	Outer	Total	Range	
0.34	0.31-0.39					Maeglin (3)
0.42	(Diam. class 8.0-9.9)					Maeglin (3)
				0.54[a]		Millikin (4)
0.39						Isenberg (5)
0.37				0.32		Erickson (6)
0.41 (Last-formed sapwood)		0.15	0.43	0.34		Lamb & Marden (22)
		0.15	0.41	0.40		Fournier & Goulet (7)
0.42	0.36-0.49 (Diam. class 7.6-8.9)					Pronin (8)
0.40	0.35-0.45					Besley (Canada) (10)
0.40						Besley (U.S.) (10)
0.38 (Sapwood) 0.37 (Heartwood)		--	0.47	0.48		IPC 3212-15
0.35 (Sapwood) 0.35 (Heartwood)		--	0.40	0.40		IPC 3212-16
0.46[b]						Isenberg (5)
0.44[b]			[illegible]	0.77[b]		Erickson (6)
			0.51[c]	0.54[c]		Cassens (32)

[a] Rough estimate based on conversion from lb OD bark per cu ft.
[b] Ovendry weight/ovendry volume.
[c] OD weight/volume at 65% RH.

The specific gravity of the total (inner + outer) bark of jack pine appears fairly close to that of the wood or perhaps slightly higher. It was impossible to obtain specific gravity measurements on the inner bark because of its extreme thinness. Overall values suggested for use in species comparisons are 0.39 for wood, and 0.43 and 0.41 for outer and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

A range in levels of extractives in wood from 3.1 to 4.2 has been reported for jack pine (see Table XIV). For between species comparisons, an extractives level of 3.9% is suggested for the wood of jack pine. Based upon information obtained from the literature and from the two trees sampled as part of this project, the bark of jack pine can be expected to have an extractives level of 15.3%. This relatively high level of extractives might cause problems in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other techniques. Extractives in pines are one of the causes of color reversion in mechanical pulps and can cause

problems when the sulfite process is used (33). A more comprehensive examination of the extractives in jack pine can be found in a paper by Sinclair and Dymond (33).

TABLE XIV

JACK PINE ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	4.2	Isenberg (5)
Wood	3.7	Isenberg (5)
Wood	3.7	Rydholm (13)
Bark	20.4	Harkin & Rowe (11)
Bark	13.3	IPC 3212-15
Bark	12.1	IPC 3212-16

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product. The principal element in the bark of jack pine having an effect on the pulp are sieve cells. Chang (1) estimated that 79.8% of the tissue elements in the inner bark are sieve cells based upon examination of cross sections. There are no true fibers in the bark of jack pine.

The short, thin-walled sieve cells (see photomicrographs) could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties.

When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve cells, would probably be extremely brittle and low in strength. Sieve cells could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of this problem.

There is also a minor amount of thick-walled, cogwheel-shaped phellem cells in jack pine similar to those found in the southern pines but fewer in numbers. Most of these cells, however, would be lost in the washing and cleaning operations. Under typical kraft pulping (48-52% yield), phellem cells usually separate and, as separate entities, should not cause serious problems. However, it appears that in high yield pulping, many of these phellem cells could remain in clumps and cause so-called "fisheyes" in certain grades of paper much like clumps of sclereids do in hardwood pulps and certain softwoods (hemlock, fir, spruce).

As a check on pulp yield and the nature of the material produced from jack pine, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micro-pulping Procedure. Table XV summarizes the results of this investigation. Micro-pulping of jack pine bark resulted in a yield of 18 to 19% solids. When screened, the coarse screens (60 and 100 mesh) retained most of the sieve cells and a minor amount of phellem cells. The on 150-mesh screen retained small amounts of sieve and phellem cells. The on 200-mesh and through 200-mesh screens contained most of the phellem cells and a small amount of sieve cells. Figure 13 illustrates the type of material on the 60- and 150-mesh screens.

TABLE XV

JACK PINE MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-15	Sample No. 3212-16	Remarks[a]
Yield, % solids	18.0	19.3	
Fraction			
On 60 mesh, %	17.6	9.0	The furnish of the fraction contained sieve cells (100-%) with traces of thick-walled, cogwheel-shaped phellem cells (< 1%), parenchyma and thin-walled peridermal cells (< 1%). The length of the sieve cells contained in the fraction was: (1) Arithmetic av. length — 1.25 mm, (2) Weighted av. length — 1.51 mm
On 100 mesh, %	8.9	10.2	The fraction contained principally sieve cells (95+%) with a small percentage of thick-walled cogwheel-shaped phellem cells (< 5%) and a trace of parenchyma and thin-walled peridermal cells (< 1%)
On 150 mesh, %	5.6	9.1	The fraction contained sieve cells (70-80%), thick-walled cogwheel-shaped phellem cells (20-30%) and a small percentage of parenchyma and thin-walled peridermal cells (< 5%)
On 200 mesh, %	6.8	13.1	The fraction furnish contained thick-walled, cogwheel-shaped phellem cells (30-40%), parenchyma and thin-walled peridermal cells (30-40%) and sieve cells (20-30%)
Through 200 mesh, %	61.1	58.6	The fraction contained large percentages of thick-walled, cogwheel-shaped phellem cells (50-60%), parenchyma and thin-walled peridermal cells (40-50%) and a trace of sieve cells (< 1%)

[a]Percentages given are on a dry weight basis.

Figure 13. The 60-Mesh Screen (Top) Contained Principally Sieve Cells (100-%). The 150-Mesh Screen (Bottom) Contained Sieve Cells (70-80%) and Thick-Walled Cogwheel-Shaped Phellem Cells (20-30%). Magnification — 75X. Symbols Include Sieve Cells (SC) and Phellem Cells (PC)

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 18 or 19 grams of solids will result. Of this 18 or 19 grams, about 4 grams (4%) of sieve cells and <1 gram (1%) of phellem cells will be produced. This assumes that only the material on the 60- and 100-mesh screen would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Wood/bark adhesion values were measured for jack pine samples collected July 17 (growing season) and December 3 (dormant season). Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured. After testing, the samples were examined to determine the location of the zone of failure. Figure 14 illustrates the zone of failure for jack pine during both the growing and dormant seasons. During the growing season, wood/bark adhesion was low (4.0 kg/cm^2) and the failure zone was located between immature xylary initials in the proximity of the cambium zone. Secondary thickening of the walls of these cells was still in process. All cells in the last-formed growth ring were earlywood.

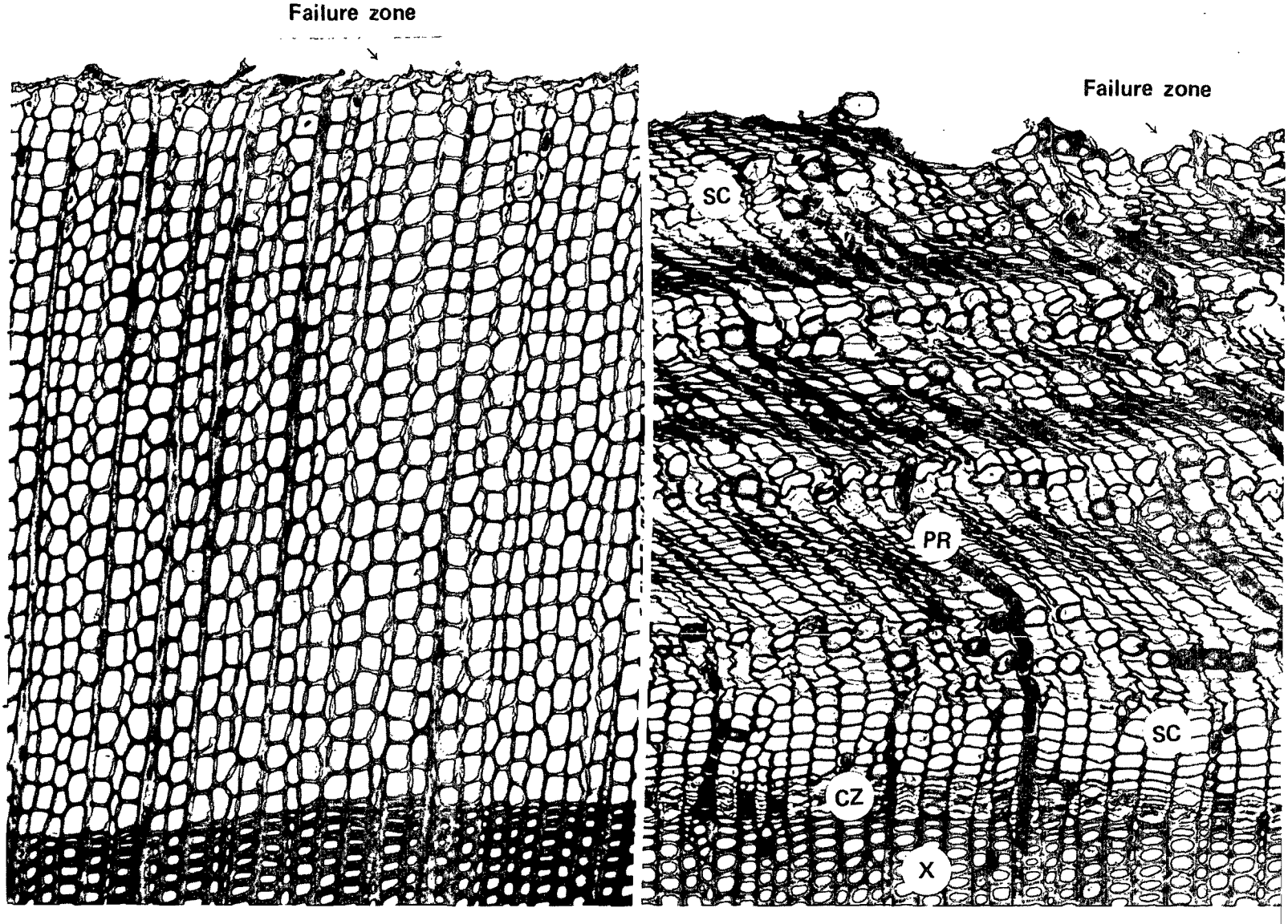

Figure 14. Illustrated is the Jack Pine Failure Zone for Both the Growing Season (Left) and Dormant Season (Right). The Growing Season Failure Occurred Between Immature Newly-Formed Xylem Fibers (XF) in the Proximity of the Cambium Zone. During the Dormant Season (Right), the Failure Zone was Located in the Inner Bark Between Sieve Cells and Phloem Parenchyma Cells Located Approximately 1 mm from the Cambium Zone. Included in the Photomicrograph are Xylem (X), Cambium Zone (CZ), Sieve Cells (SC), and a Phloem Ray (PR). Magnification — 125X

During the dormant season, wood/bark adhesion increased to 10.7 kg/cm^2 and the failure zone was found to be located in the inner bark (secondary phloem) between sieve cells and phloem parenchyma located approximately 1 mm from the cambium zone.

As a result of measurement data taken on the species included in Appendix Table XXVIII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids and a lack of phloem fibers seem to be associated with low dormant season wood/bark adhesion and low bark strength.

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips). Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

Erickson (16) reported 9 and 12% bark in fresh bolewood and topwood of jack pine (mean of 14 samples). The percent of bark separated from wood during chipping of fresh bolewood varied from 72.5% in January to 98.2% in July. For fresh topwood, the worst month was November with 47.2% separation and the best month was May with 98.4% separation. In a single pass through a compression debarker, 95.3% of bolewood was recovered with a residual bark content of approximately 3.2% (original input of bark 8.1%). Compression debarking the topwood resulted in 92.4% wood recovery with a residual bark content of

approximately 3.8% (original bark input 10.7%). In another paper, Erickson (34) showed good results with compression debarking of chips 3/8 inch or larger. Chip sizes of 3/16 inch would require additional processing. Mattson (35) found that chip piles stored for one year suffered more wood loss in compression debarking than did fresh chips (39% vs. 9%). However, he did not feel his results were conclusive because the chip piles were relatively small.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XVI summarizes the bark strength and toughness tests made on the wood and bark of jack pine.

TABLE XVI

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF JACK PINE[a]

Material	Strength	Toughness
Wood	--	0.34
Inner Bark	2.3	--
Outer Bark	2.3	0.07

[a]Determinations average of two different trees.

There were no differences in bark strength values between the inner and outer bark of jack pine. The toughness values for the wood were relatively low although considerably greater than the bark values. The low toughness values obtained for wood, however, make it appear that hammermilling or a similar technique might not work well on this species. The very low toughness and strength values for the bark are probably related to the lack of fiber and high percentage of sieve cells in jack pine.

Summarized in Table XVII are the results of the hammermilling tests run on jack pine wood and bark. Hammermilling, followed by screening, can be expected to result in only a very modest reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled and the material on the 14-mesh screen retained, the result was a 5% loss in wood and a 26% reduction in bark. The 26% reduction in bark is among the lowest of any of the species tested thus far with the wood loss being intermediate. These results confirm conclusions drawn from the bark toughness test. Figure 15 illustrates the effect of hammermilling on wood and bark of jack pine. It is possible that a quick separation could be made by screening, hammermilling the

TABLE XVII

SUMMARY OF HAMMERMILLING TEST ON JACK PINE

Tree No.	Type Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-15	Bark	18	34	18	7	8	15	Too hard to distinguish inner from outer bark, although since inner bark comprises such a thin layer, must be mostly outer bark on all screens
	Sapwood	55	36	6	1	<1	2	
	Heartwood	56	34	6	2	1	1	
3212-16	Bark	12	22	42	5	6	12	Too hard to distinguish inner from outer bark, although since inner bark comprises such a thin layer, must be mostly outer bark on all screens
	Sapwood	52	36	7	2	2	2	
	Heartwood	52	33	8	2	2	2	

[a]Standard soil screen sizes: 5 mesh has 5 wires per inch and an opening of 4.0 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.0 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.

fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method. It is also possible improvements could be made in screening by taking advantage of the differences in configuration of wood and bark chips evident in Fig. 15 (18, 19). Summary Table XXV compares bark strength, toughness and reaction to hammermilling of jack pine to other species tested thus far.

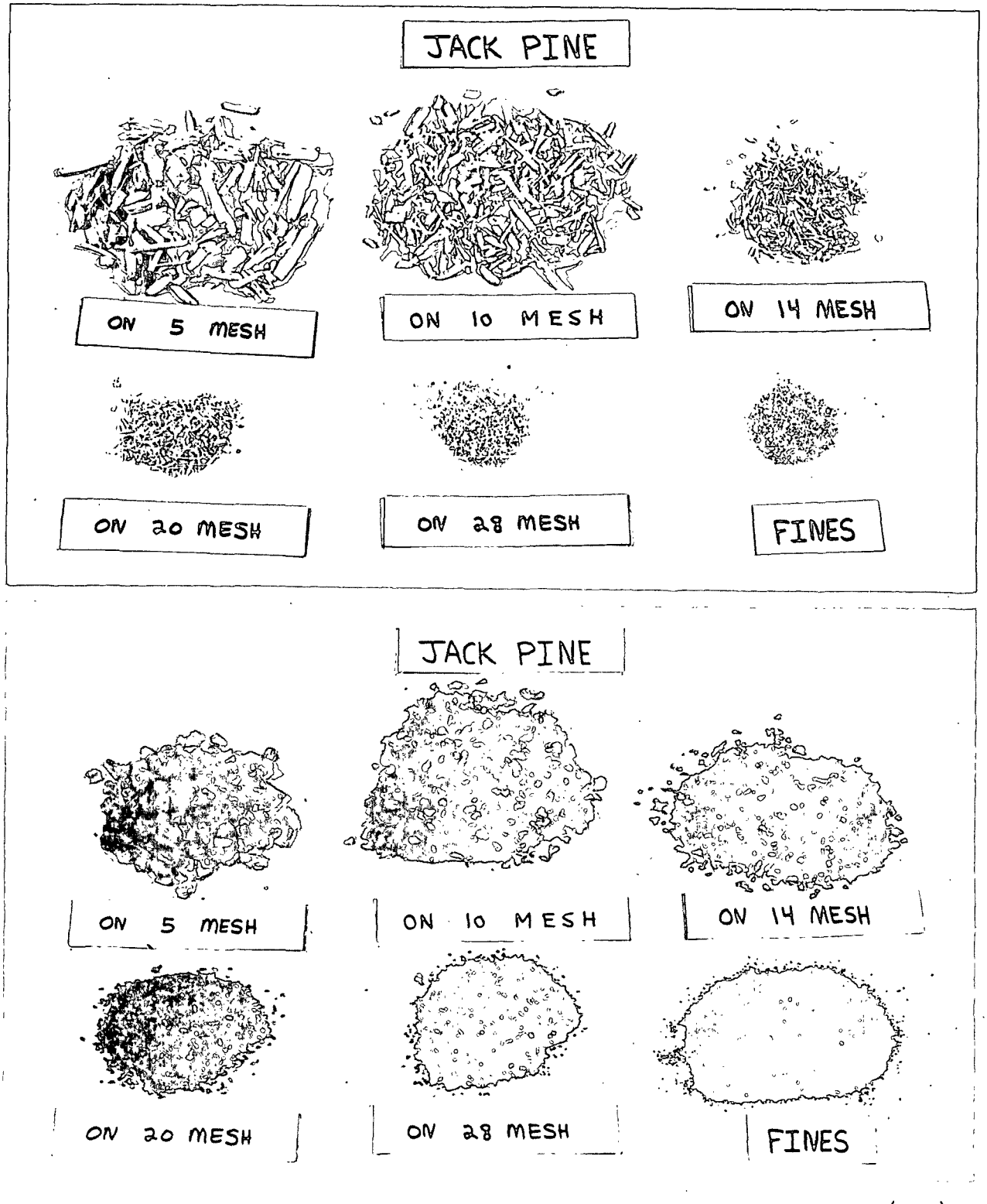

Figure 15. Illustrated is the Effect of Hammermilling on Jack Pine Wood (Top) and Bark (Bottom)

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two jack pine trees (IPC 3212-15 and IPC 3212-16) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in the terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Since the inner bark of jack pine is so thin, no samples could be obtained for density determinations. However, the outer bark seemed to have approximately the same density as the whole bark samples making it appear the outer bark would behave similarly to total bark under flotation conditions.

Figure 16 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water-flotation studies, because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that segregation through water flotation would be difficult to achieve. Both wood and bark chips could be expected to float (density less than 1) even at very high moisture contents (bark slightly higher in density than the wood). Julien, et al. (21) also found the densities of jack pine wood and bark chips overlap significantly at equal moisture contents. Both Robins (20) and Plahutnik (36) also found jack pine a difficult species to segregate through water flotation. Robins also used a polymer solution (SG = 1.062, viscosity - 2.82 cp), hoping to plug the small wood pores while leaving

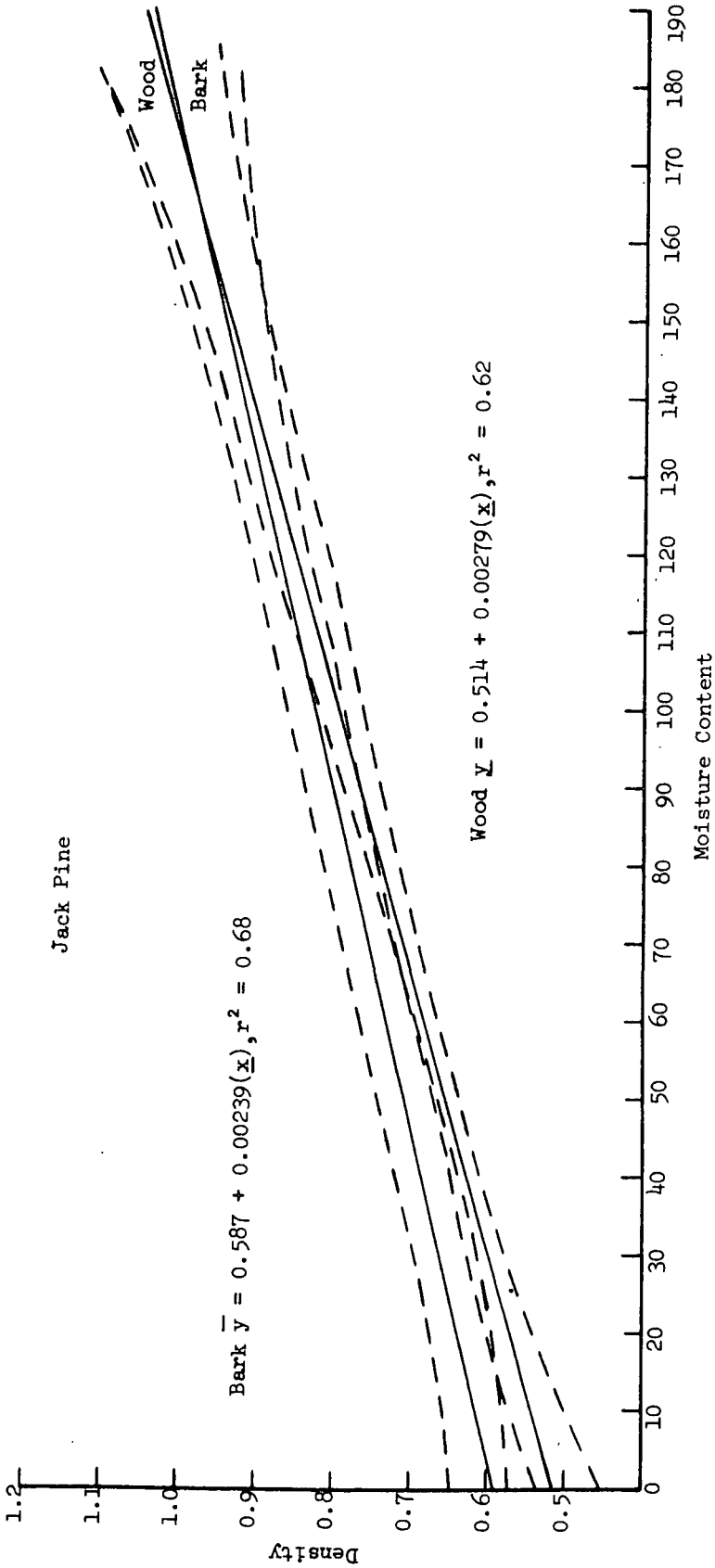

Figure 16. Illustrated is the Relationship Between Basic Density and Moisture Content for Jack Pine. The Dashed Lines are Two Standard Deviations Above and Below the Mean

the larger bark pores unaffected. Use of this solution improved the results for jack pine and he felt that an even more concentrated polymer solution might plug the wood to such a degree that it would float even if enough pressure were applied to cause the bark to sink. Plahutnik found that with a steaming and compression debarking pretreatment and after 60 psig at one minute in 0.1% fluorocarbon FC-128 solution the final bark content was 1.5% with a wood recovery of 92.2%. However, the percent bark in the original sample was only 3.3%, much lower than would normally be found in a wood/bark chip mixture.

Dwell Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar, and moisture uptake is similar, considerable difficulty in segregation can be anticipated. Time required for chip samples to sink decreases as the sample moisture content at the start of the trial increases.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table XVIII summarizes the results for jack pine. Substantiating the density determinations, only in one sample of sapwood did 7.3% of the sapwood sink after four hours.

TABLE XVIII

SUMMARY OF DWELL TIME RESULTS FOR JACK PINE[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-15 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-15 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-15 Heartwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-16 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-16 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	7.3	92.7
IPC 3212-16 Heartwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

DATA INTERPRETATION

Jack pine bark is quite thin with the narrow inner bark being approximately the same width as a rhytidome layer. There is no true fiber in jack pine but sclereids are also absent. Instead, there is a minor amount of thick-walled, cogwheel-shaped phellem cells.

Micropulping of jack pine bark, followed by examination of the material retained on the 60- and 100-mesh screens, indicates that for every 100 grams of bark that is pulped, about 4 grams of sieve cells and <1 gram of phellem cells will be produced. As with white spruce, the sieve cells could be used as filler material in paper but probably would not contribute in any useful way to paper properties. However, because of the thin nature of the bark, the lack of sclereids and the small amount of phellem cells, this species is also a good prospect for pulping with the wood.

Separation of wood and bark through action of the chipper is good during the growing season but is much less successful during the dormant season. Compression debarking appears to be a method worthy of consideration with 95% of the wood recovered. The residual bark content was 3% out of an original bark input of 8%.

Water flotation is not worthy of consideration as a segregation technique as the wood and bark are very close in density at similar moisture contents. Other investigators have obtained similar results.

Hammermilling resulted in a very modest reduction in bark levels. In IPC trials, hammermilling followed by screening resulted in only a 26% reduction in bark and a 5% loss of wood. However, it is possible a quick separation could be made by screening, hammermilling the fractions high in bark and rescreening. It is also possible that screening could be improved by taking advantage of the configuration differences between wood and bark.

RELATED LITERATURE

As with the two previous species, there are a number of papers that deal with the mechanics of segregating wood/bark chip mixtures. They include papers by Auchter and Horn (22), Sturos (23, 30), Hooper (24) plus an additional one by Arola and Erickson (37). The previously cited paper by Hale (28) gives information on bark thickness while one by Martin (38) gives information on volumetric shrinkage values for bark.

BARK AND WOOD PROPERTIES OF EASTERN COTTONWOOD
(Populus deltoides Bartr.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Eastern cottonwood grows throughout most of the eastern half of the United States with the exception of the higher Appalachian areas. Found along streams and bottom lands, its range extends from southern Quebec and Ontario west to southeastern North Dakota, south through western Kansas, Oklahoma and southern Texas, to northwestern Florida and Georgia. Its best commercial development occurs on the alluvial bottom lands of the lower Mississippi River and its tributaries. Cottonwood is seldom found at elevations of more than 15-20 ft above the average level of nearby streams.

Abundant and continuous moisture throughout the growing season is as important to cottonwood as the texture and fertility of the soil. Humid climate and moist, medium-textured soil with good internal drainage promotes the best growth of cottonwood. Free-growing trees on such sites will exceed 120 ft in height at age 30. One of the tallest trees east of the Rocky Mountains, cottonwood attains heights of 175-190 ft, and diameters of 4-6 ft are not uncommon in mature stands.

WOOD AND BARK MORPHOLOGY

Wood

The general structure of the wood of eastern cottonwood is similar to that of the aspens. The wood is semiring to diffuse porous. The growth rings are distinct but inconspicuous and often very wide. The small xylem vessels are barely visible with the naked eye in the earlywood and decrease gradually in size throughout the latewood. The vessels are solitary or in radial rows of two or

more. Parenchyma are terminal, the narrow light-colored lines being more or less distinct. The rays are very fine, scarcely visible with a hand lens and are unstoried, uniseriate, and essentially homogeneous.

Eastern cottonwood fibers, thin to medium thick-walled and occasionally gelatinous, range from 25-40 μm in diameter, with an average length of approximately 1.0 mm. Large earlywood vessels are 100-150 μm in diameter while the latewood vessels are about half this size. Vessel elements vary in number from 30-145 per square millimeter.

Bark

Thin, smooth and light yellowish-green in young stems, the bark of the eastern cottonwood becomes ash-grey with age, dividing into thick, flattened or rounded ridges separated by deep fissures. In structure, the bark of species of Populus is quite alike, especially their secondary phloem. In the trees used in this study, the outer bark ranged from 69% to 77% of the total bark thickness by weight. Figure 17 illustrates a cross section of eastern cottonwood wood and bark. Appendix Table XXVII describes the trees used in this study.

Anatomical Structure of Mature Bark

In general, eastern cottonwood is rather similar in structure to quaking aspen and bigtooth aspen except in the periderm, where in cottonwood the phellem cells are mostly thin-walled and comparatively loose in arrangement. The last-formed periderm consists of a layer of phellogen, 2-3 layers of phelloderm and layers of thin and thick-walled phellem or cork. Small groups of sclerified cells are often associated with the thick-walled cells, or close to them.

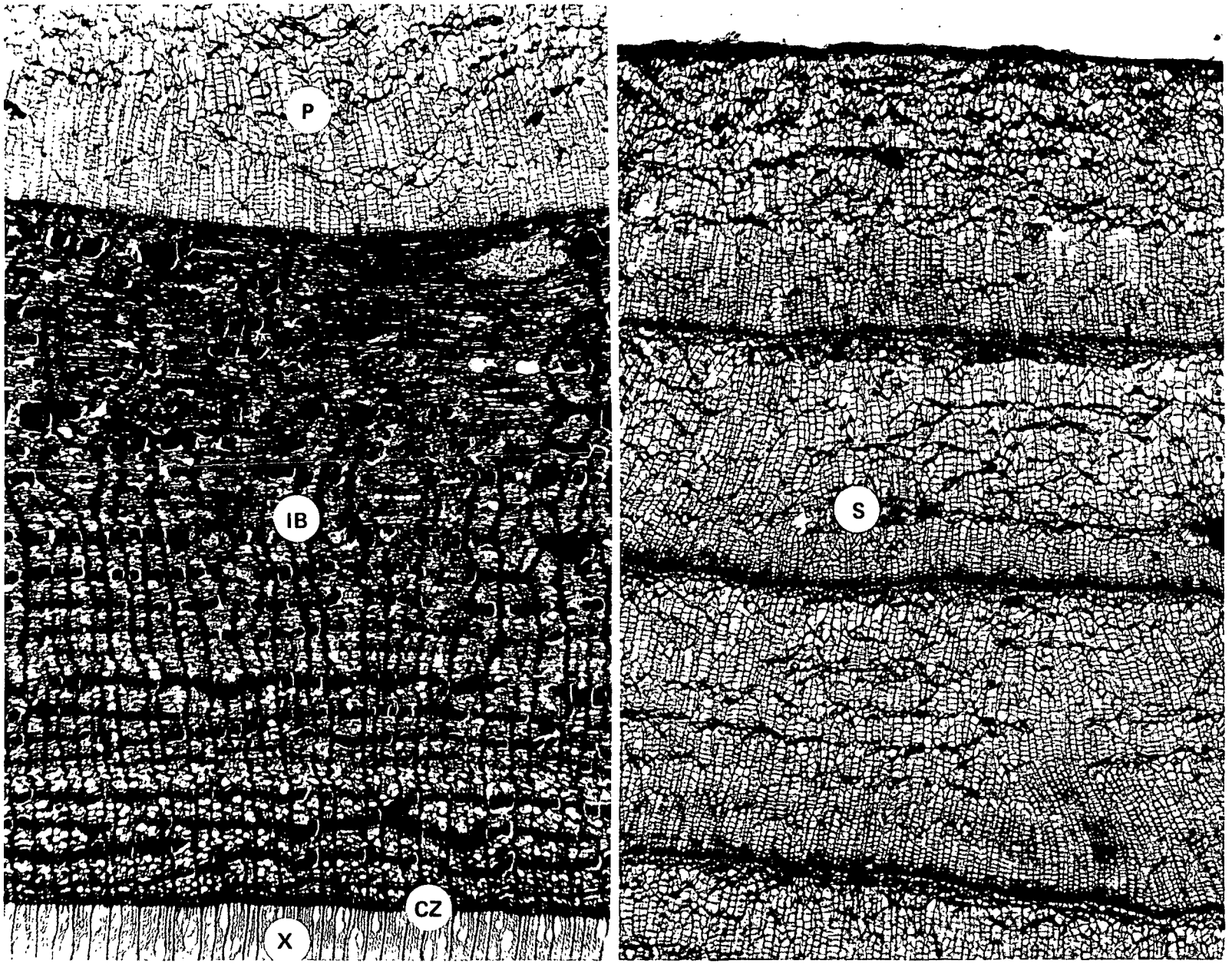

Figure 17. Cross Section of Cottonwood. Photomicrograph on Left Shows Xylem (X), Cambium Zone (CZ), Inner Bark (IB) and the Last-Formed Periderm (P) of the Outer Bark. Tangential Bands of Sieve Tubes and Phloem Fibers are Aligned in Regular Alternations in the Secondary Phloem. Sporadic Groups of Sclereids are Present in the Inner Bark Aligned with the Fiber Bands. Strands of Crystalliferous Parenchyma Often Appear at the Margin of the Fiber Bands. The Strands Consist of Chambers each Containing a Single Crystal of Calcium Oxalate. Photomicrograph on the Right is a Cross Section of the Outer Bark Showing the Periderm. Groups of Sclerenchyma Cells (S) are Present in the Periderm. Magnification — 35X

The inner bark (secondary phloem) of eastern cottonwood is composed of sieve tubes with companion cells, parenchyma cells, uniseriate phloem rays and sclerenchyma (phloem fibers and sclereids). The thin-walled sieve tubes, which may be solitary but are mostly in small groups of 2-5, together with companion cells and phloem parenchyma, are bounded radially by uniseriate rays and tangentially by bands of sclerenchyma or phloem fibers. The sieve tubes are oval to polygonal in cross section and vary from 25 µm to 50 µm in diameter. Quite variable, sieve tube elements are usually 600 µm to 1 mm long. The parenchyma cells are distributed in a more or less reticulate formation among the sieve tubes. On cross section, these cells are round to oval and average approximately 20 µm in diameter.

Narrow tangential bands of phloem fibers closely and evenly spaced are characteristic of the inner bark of eastern cottonwood. The bands of fibers average approximately 60 µm in radial dimension and consist of mostly 3-4 fibers in radial rows. Occasionally, a small portion of the band may be more than 200 µm in width and consist of 10-12 fibers in radial rows. On cross section, the phloem fibers are polygonal in shape and average approximately 20 µm in diameter at the broadest portion. The cell walls are very thick, about 10 µm, and the lumen is narrow, approximately 2-3 µm. The fibers average approximately 1.0 mm in length. Small groups of thick-walled sclereids appear in the outer part of the inner bark of the samples examined.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and sclereids are expected to be useful in determining the need

and possible methods of separating and segregating wood/bark chip mixtures*. Whenever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table XIX summarizes the information available on wood and bark of eastern cottonwood and, whenever possible, information on bark has been separated into inner and outer bark. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. It should be noted that one of the values in Table XIX is ovendry weight divided by ovendry volume. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report under the section Water Flotation Behavior compares the basic density (green weight divided by green volume) of eastern cottonwood at several moisture contents.

An average specific gravity (ovendry weight/green volume) of approximately 0.38 appears appropriate for the wood of eastern cottonwood. Our limited data do not show much of a difference between heartwood and sapwood.

The specific gravity of the total (inner + outer) bark of eastern cottonwood appears slightly lower than that of the wood. Our limited data show the inner and outer bark of eastern cottonwood to be fairly close in specific gravity with the inner bark perhaps slightly lower. Overall values suggested for use in species comparisons are 0.38 for wood and 0.29, 0.32 and 0.31 for inner, outer and total bark.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

TABLE XIX

EASTERN COTTONWOOD SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood		Bark				Reference and Remarks
Average	Range	Inner	Outer	Total	Range	
0.39 (Core, diam. class 6.0-7.9)						Maeglin (3)
0.37						Isenberg (5)
0.38						Jett & Zobel (39)
			0.37			Fournier & Goulet (7)
0.37						Besley (U.S.) (10)
0.40 (Sapwood) 0.36 (Heartwood)		0.28	0.28	0.28		IPC 3212-60
0.35 (Sapwood) 0.36 (Heartwood)		0.30	0.32	0.31		IPC 3212-61
0.43[a]						Isenberg (5)

[a]Ovendry weight/ovendry volume.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

A range in levels of extractives in wood from 0.9 to 1.8% has been reported for eastern cottonwood (see Table XX). For between species comparisons, an extractives level of 1.4% is suggested for the wood of eastern cottonwood. Based upon information obtained from the two trees sampled as part of this project, the bark of eastern cottonwood can be expected to have an extractives level of 7.9%. This is a relatively low level, considerably less than the 15% level of extractives reported for quaking aspen.

TABLE XX

EASTERN COTTONWOOD ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	1.8	Isenberg (5)
Wood	0.9	Bray & Paul (40)
Wood	3.3[a]	Moore & Effland (41)
Bark	8.8	IPC 3212-60
Bark	7.0	IPC 3212-61

[a]Extractives determined on an average of outer rings 17-19 and outer rings 20-22.

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product. The principal element in the bark of eastern cottonwood having an effect on the pulp are phloem

fibers. There is also a minor amount of sieve cells. In such small quantities, the sieve cells would probably not contribute much to the resulting paper nor should they cause serious problems with felt plugging or drainage.

As described in the section on bark morphology, there occurs in the inner bark (secondary phloem) tangential bands of heavily lignified fibers described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the principal bark elements expected to survive chemical pulping and contribute to overall pulp yield and sheet strength.

As a further check on pulp yield and the nature of fibrous material produced from eastern cottonwood, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. For a complete description of this procedure see the section on Experimental Procedures in Report One. Table XXI summarizes the results of this investigation. Micropulping eastern cottonwood bark resulted in a yield of 34 to 37% solids. When screened, the coarse screens (60 and 100 mesh) retained most of the fibrous material. The on 150-mesh screen had small percentages of fibers and sieve tubes. The on 200-mesh and through 200-mesh screens contained high percentages of parenchyma and peridermal cells. Figure 18 illustrates the type of material on the 60- and 100-mesh screens.

Unfortunately, the bark samples were contaminated with a small amount of xylem fibers. However, it still appears that for every 100 grams of bark that is pulped, about 35 grams of solid will result. Of this 35 grams about 9 grams (9%) of usable fiber, <1 gram (1%) of long, thin-walled sieve tubes and <1 gram (1%) of other material, principally parenchyma cells will be produced.

TABLE XXI

EASTERN COTTONWOOD MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-60	Sample No. 3212-61	Remarks[a]
Yield, % solids	36.6	34.3	
Fractions			
On 60 mesh, %	25.6	21.9	The fraction contained principally phloem and xylem fibers (95+%) with a small percentage of vessel elements from the xylem (< 5%) and traces of parenchymatous cells (< 1%) and crystalliferous parenchyma (< 1%). Unfortunately, the fraction was contamined with xylem cells. The length of the fibers was: (1) Arithmetic av. fiber length — 1.03 mm, (2) Weighted av. fiber length — 1.07 mm
On 100 mesh, %	4.7	4.7	The fraction contained principally phloem and xylem fibers (80-90%) with smaller percentages of sieve tubes (10-20%) and parenchymatous cells (< 5%) and a trace of vessel elements (< 1%)
On 150 mesh, %	1.7	2.0	The fraction contained a large percentage of sieve tubes (60-70%) with smaller percentages of phloem and xylem fibers (20-30%) and parenchymatous cells (5-10%)
On 200 mesh, %	2.3	2.2	The fraction contained large percentages of parenchyma and peridermal cells (40-50%) and sieve tubes (30-40%), a smaller percentage of xylem and phloem fibers (10-20%), and < 5% crystalliferous parenchyma cells
Through 200 mesh, %	65.7	69.2	The fraction contained principally parenchyma and peridermal cells (70-80%) with a smaller percentage of crystalliferous parenchyma (20-30%) and traces of sieve tubes (< 1%) and sclereids (< 1%)

[a]Percentages given are on a dry weight basis.

Figure 18. The 60-Mesh Screen (Top) Contained Principally Phloem Fibers with Xylem Fiber Contamination. These Fibers Amounted to 95+% of the Fraction. The 150-Mesh Screen (Bottom) Contained a Large Percentage of Sieve Tubes (60-70%) with Smaller Percentages of Phloem and Xylem Fibers (20-30%) and Parenchymatous Cells (5-10%). Magnification — 75X. Symbols Include Phloem Fibers (PF) and Sieve Tubes (ST)

This assumes that only the material on the 60- and 100-mesh screens will end up in and contribute in any significant way to the final product. The remaining material will be lost in washing and cleaning operations. These results compare very closely with those obtained for quaking aspen. Quaking aspen had a yield of 34% solids of which 10% was usable fiber and 2% was sieve cells.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured for appropriately collected samples. Wood/bark adhesion in eastern cottonwood was studied extensively in Project 2929 (Progress Report Three) and the work was not repeated but a summary of the results of earlier investigations follows.

Wood/bark adhesion in eastern cottonwood collected near Mobile, Alabama, ran from 4.4 kg/cm^2 during the peeling season to in excess of 13.5 kg/cm^2 during the dormant season with averages of 5.2 kg/cm^2 (growing season) and in excess of 10.8 kg/cm^2 (dormant season). The high dormant season value is probably related to the amount of fiber found in the bark of eastern cottonwood. Northern sources of eastern cottonwood exhibited approximately the same values for dormant season adhesion (12.8 kg/cm^2). The peeling season for the southern sources of

eastern cottonwood ran from about the beginning of April to the end of July. Figure 19 illustrates the zones of failure for eastern cottonwood.

Cottonwood, like several other hardwoods tested, had a dormant season zone of failure in the inner bark sieve tubes and parenchyma cells just outside the cambium. Like quaking aspen, the cottonwood tended to fail just inside or along the last-formed band of phloem fibers. During the peeling season, the zone of failure moved into the zone of newly-formed xylem and xylem initials. The zone of failure extended into the wood a maximum of 6 to 8 cells, always staying inside the cambium zone and outside the partially lignified xylem elements. Upon cessation of cambium activity in the fall, the failure zone again moved into the inner bark.

As a result of measurement data taken on the species included in Appendix Table XXVIII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids and a lack of phloem fibers seem to be associated with low dormant season wood/bark adhesion and low bark strength.

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips). Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful. Use of a ring

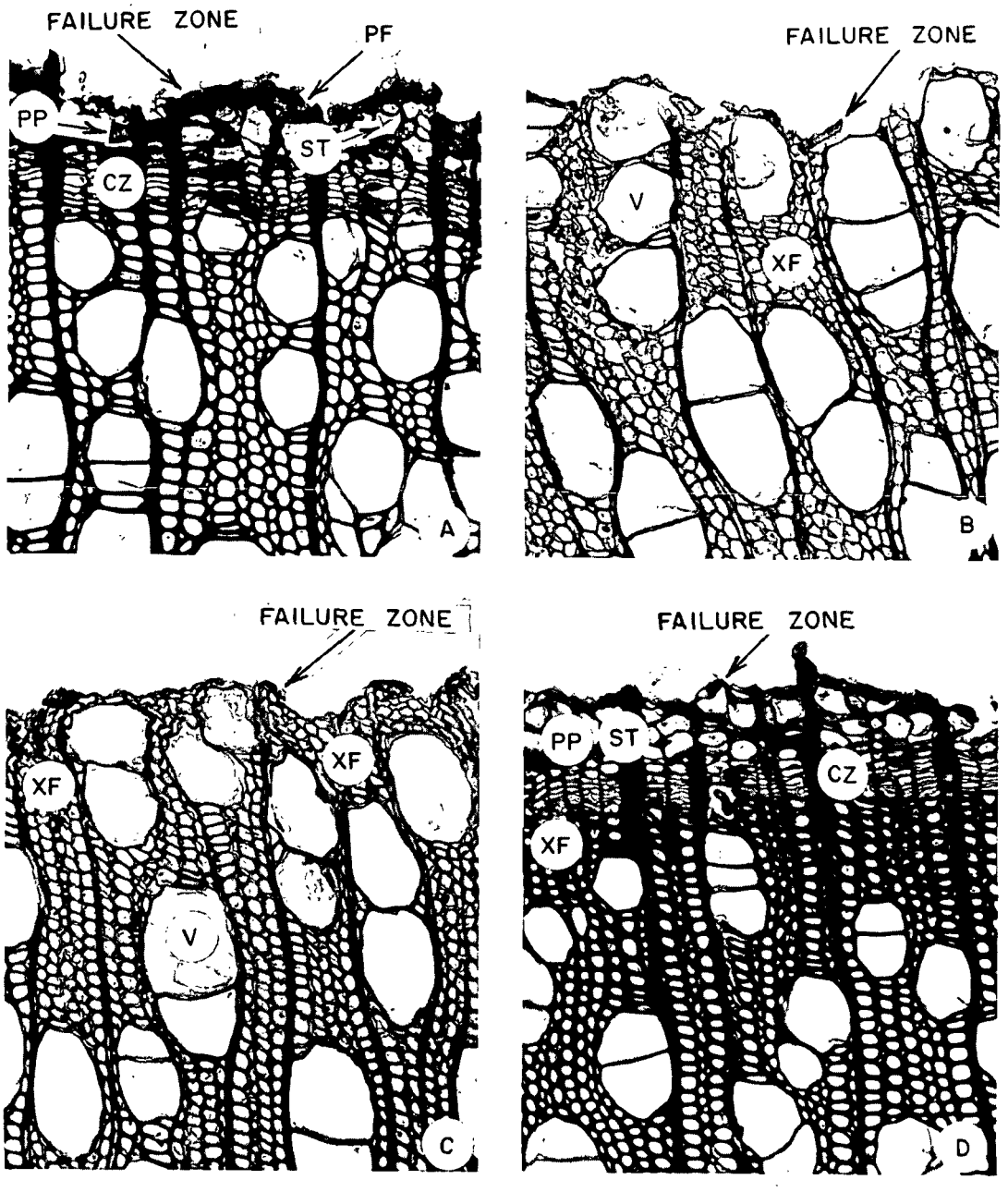

Figure 19. Illustrated are the Seasonal Changes in the Location of the Zone of Failure in Cottonwood. A — February 1 Collection, Failure in the Phloem Parenchyma and Sieve Tube Area (PP-ST) Just Outside the Cambium Zone (CZ) and Near Bands of Phloem Fibers (PF); B — May 10 Collection, Failure in Xylem Between Cambium Zone and Newly Formed Xylem Elements Showing Some Lignification; C — July 12 Collection, Failure in Xylem in Newly Formed Xylem Initials and Just Outside Xylem Elements Showing Some Lignification; D — August 16 Collection, Failure Again in the Phloem Parenchyma — Sieve Tube Area (PP-ST) and Just Outside the Cambium Zone

debarker (17) shows moderate results with a ranking of 5* from early spring to late fall and 8* in winter using steam or a hot pond. This species was considered difficult because the smooth bark does not present indentations to receive the debarking tools.

As discussed previously, several approaches were tried with hardwoods and two softwoods in Project 2929 to reduce adhesion that might have some promise. These methods included chemical, thermal, and biological methods. Eastern cottonwood was investigated in this study and an approximate ranking of the investigated species as to ease of reduction of adhesion using these methods resulted in cottonwood being the second easiest to effect adhesion reduction of the six species. These methods are discussed in greater detail in the section on Between-Species Comparisons.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

*Ranking system of 1 — easy to debark to 10 — hard to debark.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XXII summarizes the bark strength and toughness tests made on the wood and bark of eastern cottonwood.

TABLE XXII

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF EASTERN COTTONWOOD[a]

Material	Strength	Toughness
Wood	--	0.38
Inner Bark	17.7	0.14
Outer Bark	4.2[b]	0.11

[a] Determinations average of two different trees.
[b] Strength low, test samples failed during preparation, data based upon a single test.

Inner bark strength for eastern cottonwood is very high, probably due to the presence of fiber in the inner bark. The differences in toughness between wood and bark are fairly large but the high strength of the inner bark would probably have an adverse effect when attempting segregation through hammermilling or some similar procedure.

Summarized in Table XXIII are the results of the hammermilling tests run on eastern cottonwood wood and bark. Hammermilling was not an effective technique for segregating chip/bark mixtures. When the half-sized chips for the two trees investigated were hammermilled and the material on the 14-mesh screen retained, the result was a 5% loss in wood and an 18% reduction in levels

TABLE XXIII

SUMMARY OF HAMMERMILLING TEST ON EASTERN COTTONWOOD

Tree No.	Type Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-60	Bark	41	31	9	4	4	11	2/3-1/2 Inner bark found on 5- & 10-mesh screens and increasing amounts of outer bark on rest of screens; inner bark stringy
	Sapwood	71	19	3	1	2	4	
	Heartwood	78	13	3	2	1	2	
3212-61	Bark	54	21	7	3	4	11	2/3-1/2 Inner bark found on 5- & 10-mesh screens and increasing amounts of outer bark on rest of screens; inner bark stringy
	Sapwood	84	9	3	1	1	2	
	Heartwood	89	5	2	<1	1	2	

[a]Standard soil screen sizes: 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28 mesh screen has 28 wires per inch and an opening of 0.589 mm.

of bark. However, most of the bark retained was stringy inner bark. Considering the low extractives level and high amount of fiber in the inner bark, pulping the inner bark might have somerit in certain cases. Figure 20 illustrates the effect of hammermilling on wood and bark of eastern cottonwood.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is also expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of

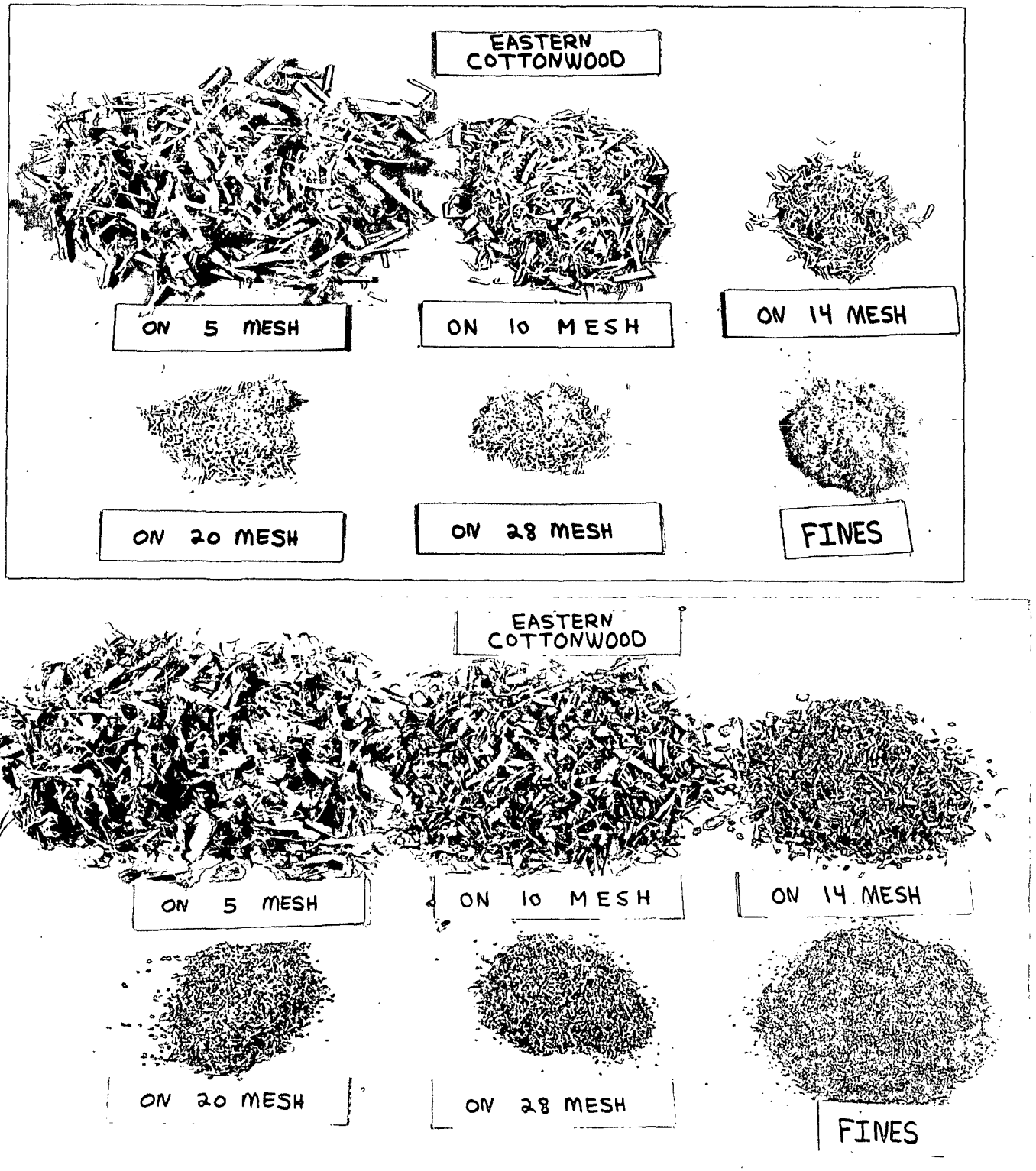

Figure 20. Illustrated is the Effect of Hammermilling on Eastern Cottonwood Wood (Top) and Bark (Bottom)

moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and the density of bark and wood. Wood and bark from two eastern cottonwood trees (IPC 3212-60 and IPC 3212-61) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. The inner bark for both trees tested appeared to have a slightly higher density than the outer bark. The density of the outer bark was similar to that of the total bark.

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in the terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

Figure 21 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies, because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that segregation would be difficult to achieve as the densities of wood and bark of eastern cottonwood are similar at the same moisture content. Perhaps if the inner and outer bark could be separated through hammermilling or some other procedure, the inner bark of eastern cottonwood could be removed as sinkers due to its higher density at comparable moisture contents.

Dwell Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar,

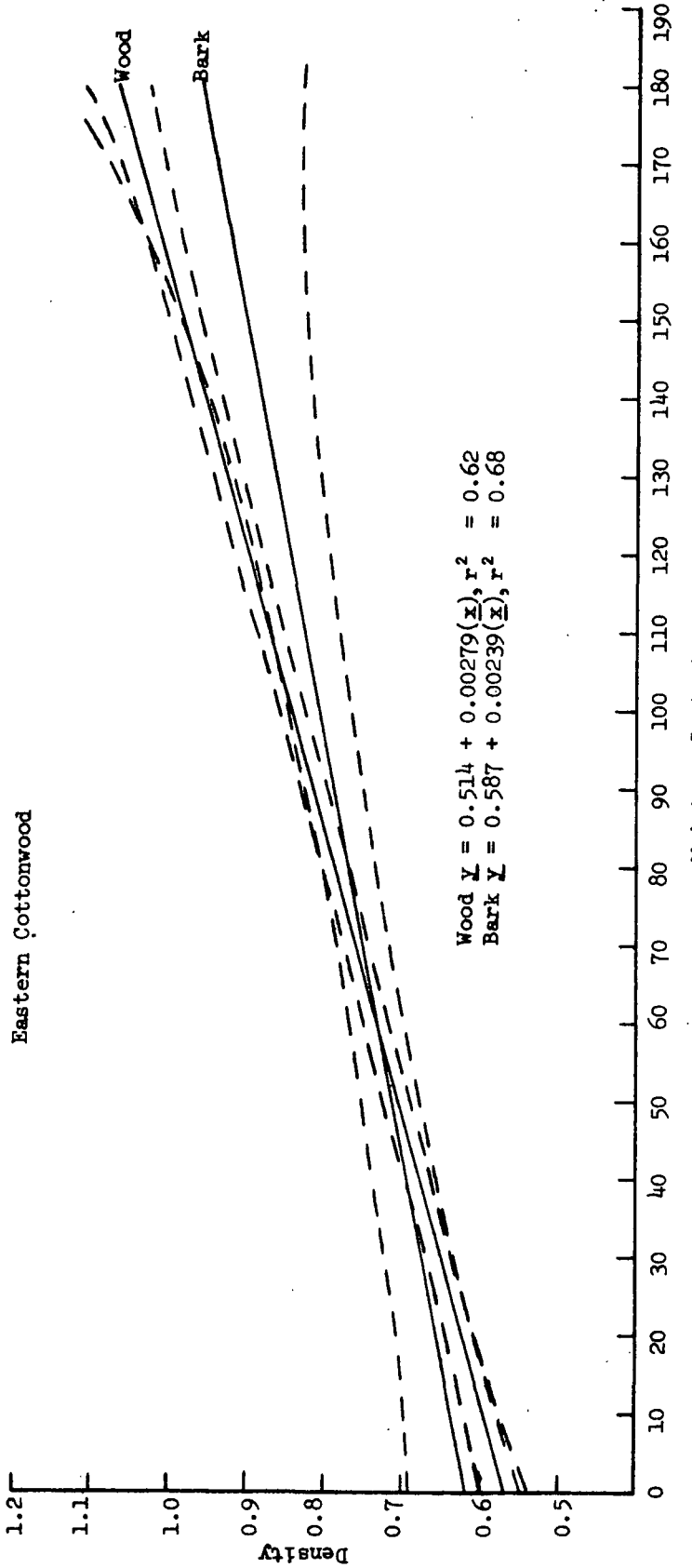

Figure 21. Illustrated is the Relationship Between Basic Density and Moisture Content for Eastern Cottonwood. The Dashed Lines are Two Standard Deviations Above and Below the Mean

and moisture uptake is similar, considerable difficulty in segregation can be anticipated. Time required for chip samples to sink decreases as the sample moisture content at the start of the trial increases.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table XXIV summarizes the results for eastern cottonwood. These results substantiate the results obtained in the density determinations.

DATA INTERPRETATION

Eastern cottonwood bark is the only one of the species investigated in this report that contains any fiber. It also lacks sclereids and the extractives content of the bark is low. This makes pulping eastern cottonwood bark more attractive than for many other species.

Although the sample of bark examined for fibrous material was contaminated with wood, it appears that eastern cottonwood bark has similar amounts of fiber as quaking aspen. Micropulping eastern cottonwood bark, followed by examination of the material retained on the 60- and 100-mesh screens, indicates that for every 100 grams of bark that is pulped, about 9 grams of usable fiber and <1 gram of sieve and parenchyma cells will be produced.

Again, separation of the wood and bark through action of the chipper is good during the growing season but much more difficult during the dormant season, particularly because its smooth bark does not present indentations to receive the debarking tools. However, chemical and thermal methods, as described in the section on Between-Species Comparisons, appear to have some promise with

TABLE XXIV

SUMMARY OF DWELL TIME RESULTS FOR EASTERN COTTONWOOD[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-60 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-60 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-60 Heartwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-61 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-61 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-61 Heartwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

eastern cottonwood as it ranked second out of the six species investigated in adhesion reduction.

Segregation of wood/bark chip mixtures through water flotation would be difficult to achieve as the densities of wood and bark are similar at the same moisture content.

Hammermilling resulted in a very modest reduction in levels of bark, with only 18% of the bark removed (5% wood loss). However, most of the bark removed was outer bark. This makes it appear possible to screen, hammermill the fractions high in bark and rescreen to remove the outer bark. This would leave the inner bark which contains the fiber.

RELATED LITERATURE

The previously cited papers by Auchter and Horn (22) and Hooper (24) deal with the economics and mechanics of segregating wood/bark chip mixtures. Hamilton and Wendel (42) discuss specific gravity and fiber length of hybrid poplars while Taylor (43) has a paper on the effect of extraction on the volume dimensions and specific gravity of solid wood blocks.

BETWEEN-SPECIES COMPARISONS

Tables XXV and XXVI provide a method of quickly comparing the basic information available for the first 12 species investigated. Summarized in Table XXV are data for conifers and in Table XXVI is information on hardwoods. As more and more data become available, increasing numbers of useful relationships are expected to develop between morphology, density, bark strength, wood/bark adhesion, and fibrous yields.

For the first 12 species investigated, the conifer barks investigated were lower in specific gravity than most of the hardwood barks (cottonwood was an exception). Conifer bark also tended to be similar or lower in specific gravity than associated sapwood. The conifer barks examined, with the exception of Douglas-fir, have no true fiber or fiberlike elements and, as a result, produce no useful fibrous yield when pulped. The fibrous yield of hardwood bark varies from 10% for cottonwood and aspen to no usable fiber in white birch. There has been no consistent pattern with regard to levels of extractives or bark toughness despite very large differences between species. Toughness, however, was consistently greater for wood than for bark and wood toughness appears to be moderately correlated to wood density.

Wood/bark adhesion during the growing season was low, similar in magnitude for all species investigated, and the zone of failure quite consistently occurred in the cambium zone or the newly-formed nonlignified wood fibers immediately adjacent to the cambium zone. Dormant season wood/bark adhesion was higher than during the growing season. Dormant season wood/bark adhesion for the hardwoods tends to be slightly higher than for conifers. Also, for most species, dormant season failure usually occurred in the partially mature sieve and parenchyma cells of

TABLE XXV

WOOD AND BARK CHARACTERISTICS OF CONIFER PULPWOOD SPECIES

Characteristic	White Spruce	Balsam Fir	Jack Pine	Loblolly Pine	Slash Pine	Douglas-fir	Western Hemlock
Specific gravity (ovendry wt./green vol.)							
Wood	0.34	0.34	0.39	0.45	0.54	0.43	0.40
Total bark	0.39	0.40	0.41	0.33	0.35	0.41	0.45
Inner bark	--	0.32	--	0.29	0.34	0.42	0.46
Outer bark	0.43	0.46	0.43	0.34	0.36	0.40	0.45
Extractives, %							
Wood	2.2	2.0	3.9	3.0	3.3	4.0	1.6
Bark	16.0	19.5	15.3	8.5	8.4	16.4	11.7
Density at 100% moisture (green wt./green vol.)							
Wood	0.70	0.75	0.79	0.88	1.10	0.815	0.80
Bark	0.83	1.07	0.83	0.57	0.72	0.825	0.85
Pulp yield, % (bark)	20.6	26.0	18.6	23.6	23.6	17.6	35.8
Usable bark fiber, %[a]	0	0	0	0	0	5	0
Sclereids remaining, %[a]	1.5	12.0	0	0	0	2	11
Fiber location[b]	--	--	--	--	--	IB-OB	--
Sclereid location[b]	IB-OB	IB	--	--	--	IB-OB	IB-OB
Wood/bark adhesion, kg/cm^2							
Growing season	4.4	2.4	4.0	5.8	3.5	3.4	3.6
Dormant season	10.3	9.0	10.7	5.5	9.1	8.0	8.2
Bark strength, kg/cm^2							
Inner bark	--	1.7	2.3	3.7	6.4	5.8	6.0
Outer bark	7.4	1.4	2.3	3.2	5.2	3.0	--
Toughness							
Inner bark	--	0.06	--	0.10	0.06	0.34	0.12
Outer bark	0.16	--	0.07	0.06	0.09	0.03	0.10
Sapwood	0.34	0.42	0.35	0.54	0.54	0.58	0.28
Hammermilling[c]							
Bark removed, %	23	44	26	34	36	28	24
Wood loss, %	4	6	5	6	5	4	3

[a] Usable bark fiber and sclereids remaining are the fibers and sclereids retained on the 60- and 100-mesh screens. The percentage given is the yield based on whole bark samples.

[b] Major proportion located in either the inner bark (IB) or outer bark (OB).

[c] Based upon simulated hammermilling followed by screening, using the on 14-mesh screen to remove bark and recover usable fiber from fines.

TABLE XXVI

WOOD AND BARK CHARACTERISTICS OF HARDWOOD PULPWOOD SPECIES

Characteristic	Quaking Aspen	Sugar Maple	White Birch	Northern Red Oak	Eastern Cottonwood
Specific gravity (ovendry wt./green vol.)					
Wood	0.38	0.59	0.49	0.56	0.38
Total bark	0.50	0.54	0.56	0.65	0.31
Inner bark	0.40	0.69	0.57	0.53	0.29
Outer bark	0.55	0.49	0.54	0.71	0.32
Extractives, %					
Wood	3.0	1.0	4.0	4.5	1.4
Bark	15	6	17	11	7.9
Density at 100% moisture (green wt./green vol.)					
Wood	0.79	1.24	1.01	1.06	0.84
Bark	1.15	1.08	1.16	1.18	0.81
Pulp yield, % (bark)	33.8	33.9	36.3	28.4	35.4
Usable bark fiber, %[a]	10	3	0	5	9
Sclereids remaining, %[a]	1	0.2	0.7	0.2	<0.1
Fiber location[b]	IB	IB	--	IB	IB
Sclereid location[b]	IB	IB	IB	IB	--
Wood/bark adhesion, kg/cm^2					
Growing season	6.4	5.8	5.1	2.5	4.4
Dormant season	11.4	10.1	12.0	8.4	13.5
Bark strength, kg/cm^2					
Inner bark	9.0	1.4	1.6	2.1	17.7
Outer bark	4.9	4.7	9.8	4.6	4.2
Toughness					
Inner bark	0.22	0.25	0.10	0.13	0.14
Outer bark	0.10	0.10	0.10	0.18	0.11
Sapwood	0.45	1.20	0.68	0.93	0.38
Hammermilling[c]					
Bark removed, %	34	29	38	34	18
Wood loss, %	5	5	6	10	5

[a] Usable bark fiber and sclereids remaining are the fibers and sclereids retained on the 60- and 100-mesh screens. The percentage given is the yield based on whole bark samples.

[b] Major proportion located in either the inner bark (IB) or outer bark (OB).

[c] Based upon simulated hammermilling followed by screening, using the on 14-mesh screen to remove bark and recover usable fiber from fines.

the inner bark located just outside the cambium zone. High wood/bark adhesion in hardwoods was often associated with large numbers of phloem fibers in the inner bark.

Hammermilling or some type of similar mechanical treatment appears promising as a method of upgrading low-quality chips high in levels of bark. The correlations between the hammermilling results and bark strength and toughness so far are quite low. It appears wood loss due to hammermilling may be weakly correlated (negatively) with density and toughness. Bark removed, on the other hand, appears to be negatively correlated with bark strength. Low bark density combined with high bark strength results in low amounts of bark removed by a hammermilling-screening procedure. Cottonwood and spruce are examples of low bark removal. Extremely low bark strength (balsam fir) resulted in a high percentage of bark removed by the hammermilling procedure. Intermediate bark strength results were poorly correlated with bark removal. The statistical analyses of the data are planned as soon as results are available for a minimum of 10 conifers and 10 hardwoods.

As reported earlier, breaking the bond between wood and bark (separation) is an important first step in any segregation procedure. A very practical way of separating bark and wood during the growing season, and in some instances during the dormant season, is through the action of the chipper. Arola (25), working with northern hardwoods, found that chipper action during the growing season gave better results than during the dormant season with less than 2% bark remaining on the chips from 4-6 and 8-inch diameter bolts. Erickson (16) obtained similar results with spruce, balsam fir and jack pine. Results during the growing season were good; however, separation during the dormant season was poor (36-72%) for bolewood and even less for the thin-barked (36-48%) branchwood,

with the poorest month for separation being the month of November. Erickson (16), working with maple, reported 96% separation during the chipping throughout the year. He also found better separation with winter-cut frozen wood over unfrozen bolts although more fines resulted.

Despite the consistent location of the wood/bark failure zone, there are, particularly in the dormant season, major differences between species in the ability of the chipper to cause separation. Preliminary investigation, Project 2929, suggests inner-bark strength and the chipper knife impact on the cambium zone are important factors. For hardwoods and possibly some conifers, the presence of fibers and sclereids in the inner bark influence inner bark strength. Bark thickness and wood density (or frozen wood) influences chipper knife impact at the cambium zone. Chipper separation during the dormant season is expected to be least effective on thin-barked, low-density woods with fiber in the inner bark. White spruce, although it has no fiber in the inner bark, is an excellent example of a thin-barked low-density wood in which dormant-season separation is poor.

As discussed previously, reduction of wood/bark adhesion is an approach that should be considered when attempting to improve segregation procedures. Because most approaches stress reducing adhesion in the cambium zone, only modest between-species differences are expected in the effectiveness of different techniques. Budget limitations have prevented research on chipper action and reduction of wood/bark adhesion from being included as part of Project 3212. Earlier investigation (Project 2929) indicated that there were a number of procedures, (chemical, thermal, and biological) worthy of further consideration. Use of green kraft cooking liquor at a temperature of 200°F and a treatment time of 60 minutes gave reduced adhesion. The main disadvantage was the high

temperature and long treatment time required. Chemical treatments were also investigated by Haas and Kremers (44) and in their work, dilute acids were effective in reducing adhesion. The principal disadvantage of the dilute acid treatment was the length of time required to effect separation, the discoloration of the wood of some species and the ineffectiveness of the treatment on dry samples.

Pressure chamber treatments also look promising with reduced treatment time needed when temperatures were in excess of 250°F. Moist storage of chips at temperatures that encourage fungus attack of the cambium zone resulted in greatly reduced wood/bark adhesion at storage times as short as 15-20 days. Another promising approach was microwave heating to create high temperatures in the moist interior of the chips. There was a moderate reduction in the wood/bark adhesion at treatment times as short as one minute. One approach that was discussed briefly earlier which appears to hold suitable promise as a method of reducing the level of bark in whole-tree chips for a number of tree species is the use of chip screening, which concentrates the bark problems in the small-sized chips (20-25% of the total input), followed by hammermilling or a similar mechanical action on the small-sized chips to upgrade the quality. Preliminary results with the southern pines suggest the large-sized chip fractions have 4-6% bark and this can be handled by a reasonable amount of in-mill equipment modifications. A minimum amount of mechanical action on the low-quality chips is expected to cause a 5-6% wood loss and a 34-36% reduction in levels of bark. Mechanical action could be continued to the point where the wood loss vs. bark removal was near optimum in view of the relative value of the two types of material for fuel vs. fiber. The screening of the mechanically-treated product, in addition to removing bark, could be expected to reduce the amount of embedded

sand and dirt. The low-quality chips not going to fuel could either be blended back into the good quality chips or pulped separately for lower quality paper or board products.

PLANS

Plans for Group Project 3212 are in the process of being modified in several ways. To date, the bark of twelve pulpwood species has been characterized, including: quaking aspen, sugar maple, white birch, northern red oak (Report One); loblolly pine, slash pine, Douglas-fir, western hemlock (Report Two); and white spruce, balsam fir, jack pine and eastern cottonwood (Report Three).

Arrangements are being made to switch the bark characterization studies from a group project to a formally (internally) funded project. This will mean instead of being supported by the present members of Group Project 3212, the support will come from the Institute's general research fund. The next four species to be characterized are sweetgum, southern red oak, northern white oak and southern white oak. This work is well under way and is expected to be completed before August 1.

Upon completion of the first 16 species, plans are to extend the program to an additional 16 species. In addition, two new determinations, total ash content and fuel value, will be added to the measurements being made on the bark. The ash content measurement is being added because of the recovery furnace scaling problems being encountered that appear to be related to increased bark levels resulting from the use of "whole tree" chips. Fuel value measurements are being added because recent major increases in energy costs make the use of bark, wood fines and low-quality, bark-contaminated chips for fuel look very attractive. Ash and fuel information will also be completed on the earlier characterized species.

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GLOSSARY

Basic density. Green weight divided by green volume.

Cambium. A cylinder, strip, or layer of meristematic cells, which divide to give cells which ultimately form a permanent tissue. The primary cambium in the stem and root gives rise to xylem and phloem, and the secondary one produces bark.

DBH. Diameter breast height (4.5 feet).

Gelatinous fiber. Fiber, the inner wall of which is more or less gelatinous, or jellylike.

Inner bark. Tissues in the cylindrical axis of a tree immediately outside the cambium; includes the region of the secondary phloem from the cambium to the last-formed periderm.

Outer bark. Tissues in the cylindrical axis of a tree immediately outside the inner bark; includes the tissues from the last-formed periderm to the outer surface of the bark.

Parenchyma. Tissue consisting of short, relatively thin-walled cells, generally with simple pits; concerned primarily with storage and distribution of carbohydrates.

Periderm. Term applied to the cork cambium (phellogen) and the tissues (phellem and phelloderm) derived from the cork cambium.

Ray. Ribbon-shaped strand of tissue extending in a radial direction across the grain.

Resin canal. An intercellular space, often bordered by secreting cells, containing resin or turpentine.

Rhytidome. A tissue cut off outside a periderm. The cells die leaving a crust made up of alternate layers of cork and dead phloem or cortex.

Sclereid. See Sclerenchyma.

Schlerenchyma. Mechanical tissue consisting of cells with thick, lignified walls and small lumens. If the cells are elongated, they are called fibers and usually occur in bundles. When the cells are oval or rounded, they are called sclereids. They occur singly or in groups.

Secondary phloem. Inner bark.

Segregation. Removal of either the wood or bark fraction from wood/bark chip mixtures.

Separation. Detachment of bark from wood.

Sieve tube. A characteristic element of phloem. It translocates food materials synthesized in the plant. The cells are living, thin-walled and in longitudinal rows. They are connected by perforations in their transverse walls, through which pass strands of cytoplasm.

Specific gravity. Ovendry weight divided by green volume unless otherwise specified.

Storied. Arranged in tiers or in echelon, as viewed on a tangential surface or in a tangential section.

Tracheid. Fibrous lignified cell with bordered pits and imperforate ends; in coniferous wood, the tracheids are very long (up to 7+ mm) and are equipped with large, prominent bordered pits on their radial walls; tracheids in hardwoods are shorter fibrous cells (seldom over 1.5 mm), are as long as the vessel segments with which they are associated, and possess small bordered pits.

Uniseriate. Arranged in a single row, series, or layer. Also said of a vascular ray which is one cell wide in cross section.

Vessel. Composite, and hence articulated, tubelike structure found in porous wood, arising through the fusion of the cells in a longitudinal row through the partial or complete disappearance of the cross walls.

Xylary initials. The newly formed vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support.

Xylem. Wood. The vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support. It consists of vessels, and/or tracheids, fibers and some parenchyma.

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APPENDIX

TABLE XXVII

SAMPLE TREE INFORMATION[a]

Species	Tree No.	Age, yr	Height, ft	DBH, inch	Location
White Spruce	3212-6	30	36.5	8.4	N. Wisconsin
	3212-35	27	33.0	8.4	N. Wisconsin
Balsam Fir	3212-13	26	42.5	7.3	N. Wisconsin
	3212-14	29	38.5	7.8	N. Wisconsin
Jack Pine	3212-15	24	42.0	8.0	N. Wisconsin
	3212-16	23	34.5	8.0	N. Wisconsin
Eastern Cottonwood	3212-60	35+	70.0	8.8	C. Wisconsin
	3212-61	30+	65.0	8.9	C. Wisconsin

[a]Additional trees were sampled for wood/bark adhesion and bark strength measurements.

TABLE XXVIII

BETWEEN-SPECIES COMPARISONS OF WOOD/BARK ADHESION

Species	Wood/Bark Adhesion, kg/cm^2	
	Peeling Season	Dormant Season
Loblolly pine	5.8	5.5
Slash pine	3.5	9.1
Douglas-fir	3.4	8.0
Western hemlock	3.6	8.2
White spruce	4.4	10.3
Jack pine	4.0	10.7
Balsam fir	2.4	9.0
Shagbark hickory	5.3	26.9
Eastern cottonwood	4.4	13.5
Quaking aspen	6.4	11.4
Bur oak	5.8	9.6
White birch	5.1	12.0
Sugar maple	5.8	10.1
Northern red oak	2.5	8.4

TABLE XXIX

BETWEEN-SPECIES COMPARISONS OF BARK STRENGTH

Species	Bark Strength, kg/cm^2	
	Inner Bark	Outer Bark
Loblolly pine	3.7	3.2
Slash pine	6.4	5.2
Douglas-fir	5.8	3.0
Western hemlock	6.0	--
White spruce	7.4	--
Jack pine	--	0.07
Balsam fir	0.06	--
Shagbark hickory	25.0	72.7
Eastern cottonwood	17.7	4.2[a]
Quaking aspen	9.0	4.9
Bur oak	4.5	7.0
White birch	1.6	9.8
Sugar maple	1.4	4.7
Northern red oak	2.1	4.6

[a]Strength low, test samples failed during preparation, data based upon a single test.